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ABSTRACT

Theory and research background regarding the teaching of concepts are presented. Procedures are given in detail on how a concept can be analyzed in order to aid in teaching and preparing instructional materials. Nine processes of science drawn from a published elementary science curriculum ("Science: A Process Approach") are treated as concepts and analyzed. The process-concepts are Observing, Inferring, Predicting, Classifying, Measuring, Using Numbers, Using Space/Time Relationships, Communicating, and Controlling Variables. Each process-concept is analyzed in terms of its definition, defining and variable attributes, examples and nonexamples, related principles, sample problems, and key vocabulary. (Author)

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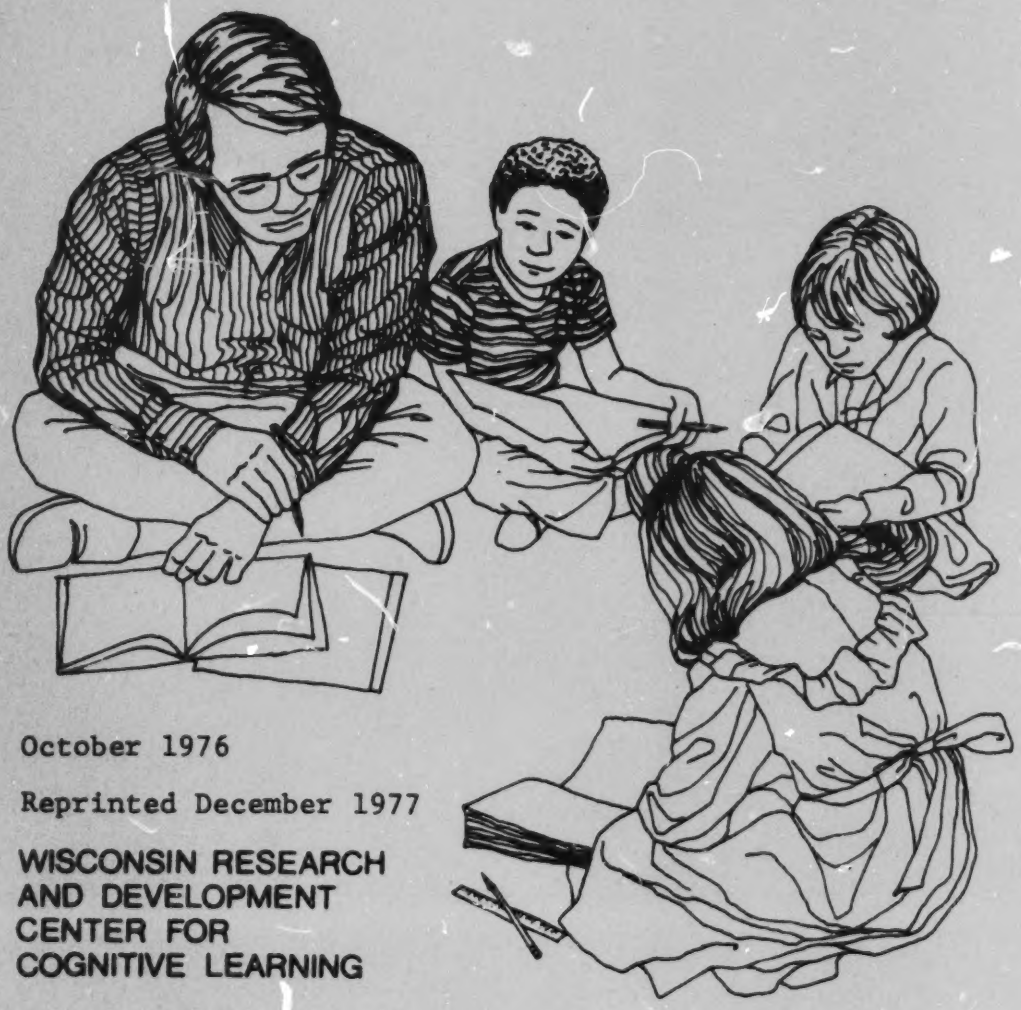
THE ANALYSIS OF NINE PROCESS-CONCEPTS IN ELEMENTARY SCIENCE

by Herbert J. Klausmeier, James E. Swanson, and Thomas S. Sipple



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by

Herbert J. Klausmeier, James E. Swanson,
and Thomas S. Sipple

Report from the Project on
Conditions of School Learning and Instructional Strategies

Herbert J. Klausmeier
Faculty Associate

Wisconsin Research and Development
Center for Cognitive Learning
The University of Wisconsin
Madison, Wisconsin

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- developing and demonstrating improved instructional strategies, processes, and materials for students, teachers, and school administrators
- providing assistance to educators which helps transfer the outcomes of research and development to improved practice in local schools and teacher education institutions

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ABSTRACT

Theory and research background regarding the teaching of concepts are presented. Procedures are given in detail on how a concept can be analyzed in order to aid in teaching and preparing instructional materials. Nine processes of science drawn from a published elementary science curriculum (Science: A Process Approach) are treated as concepts and analyzed. The process-concepts are Observing, Inferring, Predicting, Classifying, Measuring, Using Numbers, Using Space/Time Relationships, Communicating, and Controlling Variables. Each process-concept is analyzed in terms of its definition, defining and variable attributes, examples and nonexamples, related principles, sample problems, and key vocabulary.

INTRODUCTION

Researchers and curriculum developers have in the past not given proper attention to the analysis of concepts prior to doing research and developing instructional materials (Klausmeier, Ghatala, & Frayer, 1974; Markle, 1975). As a result teachers and other educational practitioners are left without firm guidelines regarding the teaching of concepts and also without suitable instructional materials. Even after many years of schooling, many high school students have not acquired a reasonable body of basic concepts and principles or the mature conceptualizing skills of which they are capable (Nelson & Klausmeier, 1974). They remain semiliterate in English, mathematics, science, and social studies, the subject matter fields in which mankind's accumulated knowledge and experience are embodied primarily in concepts and principles. Without knowledge of the essential concepts and principles, students are unable to solve the many problems of which they are potentially capable.

The lack of attention given to the analysis of concepts has prevented researchers from accurately specifying the kinds of concepts and levels of concept attainment to which their research results may generalize, and they sometimes improperly overgeneralize their results to all concepts at all levels of attainment.

Curriculum developers, including textbook authors, prepare materials to teach concepts, but often fail to include the proper kinds and amounts of information that are needed for effective instruction.

Remarkable progress has been made in the last two decades by a relatively small group of researchers in developing means for analyzing concepts and also in conducting research on concept learning and instruction. At the Wisconsin Research and Development Center for Cognitive Learning, Klausmeier and his associates have been involved in research and development activities that specify how materials may be developed to teach concepts effectively. Specifically related to the analysis of concepts, many concepts in various subject fields could and should be defined in terms of their criterial attributes, rather than by use of synonyms, examples, or context in sentences or paragraphs.

Markle and Tiemann (1969) prepared a program to teach college students and others how to teach concepts so as to avoid or reduce errors of overgeneralization, undergeneralization, and misconception. Specifically, Markle and Tiemann indicated that before teaching any concept, the concept should be analyzed by (a) developing a definition of the concept stated in terms of its criterial attributes, (b) identifying some of the irrelevant attributes of the concept, (c) identifying a set of examples and nonexamples to be used in teaching the concept, and (d) identifying a set of examples and nonexamples to be used in evaluating the extent to

which the concept has been learned. According to Klausmeier, Ghatala, and Frayer (1974) these four items in the analysis of a concept--identifying its criterial attributes, some of its irrelevant (or variable) attributes, examples of the concept, and nonexamples of the concept--may be supplemented with: identification of the hierarchy or taxonomy of which the concept is a part; illustrative principles in which the concept is embedded; illustrative problems, the solution of which involves use of the concept and/or principles; and key vocabulary in which the concept, its attributes, and the principles are expressed.

The steps in conducting a concept analysis are as follows: (1) outline the hierarchy or taxonomy of which the target concept is a part, (2) state a definition of the concept in terms of its defining attributes, (3) specify the defining attributes and some of the variable attributes of the concept, (4) provide illustrative examples and nonexamples of the concept, (5) identify some principles in which the concept is incorporated, (6) formulate problem-solving exercises involving use of the concept, and (7) develop a list of the key vocabulary associated with the concept.

Experience in developing concept analyses indicates that they have greatest utility in subsequently preparing instructional materials for any desired level of schooling when the analysis is directed toward the formal level of attaining the concept, and when the complete analysis is expressed in terminology appropriate for senior high school students rather than for young children.

However, what is subsequently included in a particular set of instructional materials or methods must be related to the level of concept attainment to be taught and to the level of vocabulary and other characteristics of the target student population. A description of the procedures for conducting a concept analysis follows, using as examples of each procedure information pertaining to the process-concept observing scientifically. Each procedure is described in some detail because a concept analysis provides much of the information needed to develop instructional materials to teach the concept.

OUTLINING A HIERARCHY OR TAXONOMY

A starting point for the analysis of a concept is outlining the hierarchy or taxonomy of which the concept is a part. Subject matter taught to children, kindergarten through high school, should be selected in the context of the structure of knowledge of the particular discipline or disciplines. This implies that the person conducting a concept analysis must know where a particular concept fits into a taxonomy or hierarchy, how it is defined by experts in the discipline, how it is used in principles, and how it is used in solving various kinds of related problems.

A taxonomy involves inclusive-exclusive relationships among classes of things whereas a hierarchy implies relationships among things ordered by some principle, such as of importance, priority, and dependency. A learning hierarchy results from an analysis of

a learning task. Three assumptions underlying this kind of analsis, and the concept of learning hierarchy, are: (1) learning tasks can be analysed into skills, (2) all persons must learn the same prerequisite skills in order to perform a particular task, and (3) the same sequence of instruction will facilitate their learning.

The hierarchical organization as shown in Figure 1 results from an analysis of the inquiry skills in science that students should learn during their elementary school years, not from an analysis of the skills essential to conducting and reporting an experiment. The diagram indicates certain relationships among the SAPA processes, which are referred to also as process-concepts. The process-concepts in the figure are drawn from Science: A Process Approach (AAAS Commission on Science Education, 1967), however, the figure itself is not. The relationships are presumed to be compatible with the SAPA curricular program. The basic processes as specified by SAPA are underlined while integrated processes are not. Arrows indicate prerequisite relationships among processes, solid lines connect coordinate or closely-related processes; and dotted lines indicate non-hierarchical linking relationships involving communicating. The arrows in the figure do indicate dependency relationships of a non-inclusive type among concepts. For example, observing events is essential and prerequisite to drawing inferences about the events or for classifying the events. In this kind of hierarchical organization of process-

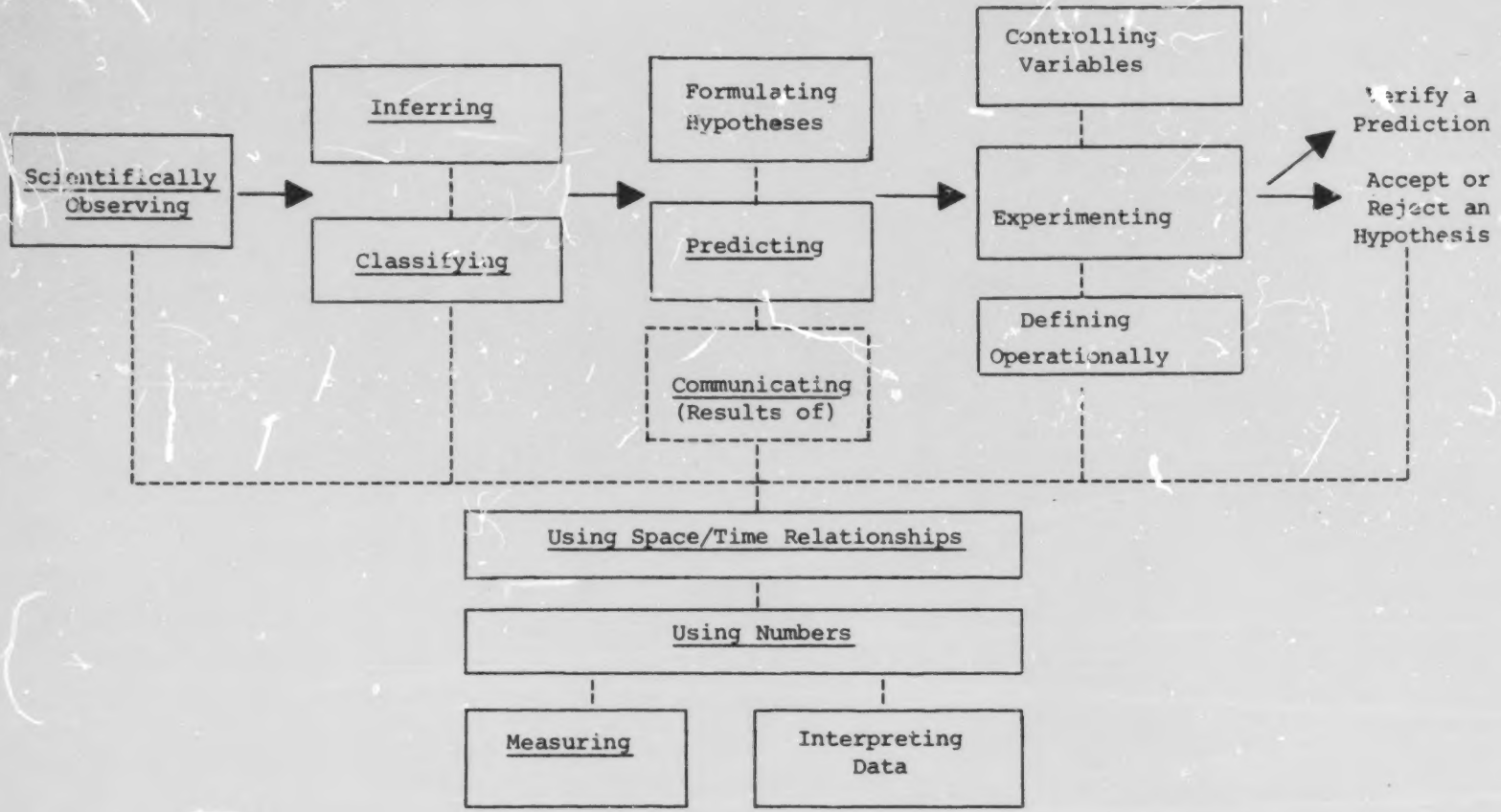


Figure 1. Relationships among the basic and integrated science process-concepts.

concepts, there may or may not be coordinate concepts at certain levels of the hierarchy.

Given below is a rationale for the postulation of the relationships in Figure 1. We first identified the process-concepts. Next, we examined the sequence of lessons that were designed to teach the processes. Not finding any rationale explicitly stated by the developers or any rationale inferrable, we took a more general approach and related the processes to scientific inquiry, more globally. Then, as outlined below, we postulated relationships among the following SAPA processes: observing, inferring, classifying, formulating hypotheses, predicting, controlling variables, defining operationally, experimentaing, communicating, using space/time relationships, using numbers, measuring, and interpreting data.

1.0 Observing is a basic process which is essential for other scientific processes.

1.1 Inferring and classifying must be based on scientific observing.

1.2 Inferences may be used in predicting specific future events or in hypothesizing (that is, formulating more generalizable statements that apply to classes of events).

1.3 In order to test predictions or to test hypotheses, the scientist first controls experimental variables, defines

operationally the manner in which data will be collected, then performs a test (the experiment).

1.4 As a result of experimenting, the scientist will have the needed information to verify a prediction or to accept or reject an hypothesis.

2.0 Communicating the results of various process activities may be linked to numerous other scientific processes.

3.0 Using space/time relationships is a process which involves spatial relationships and their change over time.

3.1 Using numbers is a process which involves measuring and interpreting data.

3.2 Using space/time relationships and using numbers may be linked to numerous other scientific processes.

Bruner (1960) made a useful distinction between the structure of knowledge in a discipline and a structure of knowledge that is learnable by students. However, the latter cannot be derived without the former. Without knowledge of both kinds of structure, one cannot proceed intelligently in the analysis of concepts. At present much of the substance of school subject matters that could be organized into either taxonomies or hierarchies is not. In the absence of this kind of information, taxonomies and hierarchies are developed by using available printed materials and also by securing assistance from persons with expertise in the particular subject matter. The hierarchy presented in Figure 1 was formulated in this manner.

DEFINING THE CONCEPT

Whether or not students will be taught a definition of the word representing a particular concept, the person conducting an analysis must know or arrive at a societally accepted definition. Further, so that examples and nonexamples may be identified for use in teaching and testing, the meaning of the word should be stated in terms of the defining attributes of the concept represented by the word. For instance:

> Observing scientifically: Using one or more of the senses in critically examining objects or events and precisely recording data about those objects or events.

The reader will recognize that observing scientifically can be treated as a concept that can be understood, as a process or skill that can be performed, or both. The authors treat it as both and presume that students' understanding it as a concept facilitates their learning to carry it out as a process.

Word definitions stated in terms of defining attributes cannot always be found in dictionaries. Definitions given in abridged dictionaries are usually synonyms, examples, or uses of the word in context. These also appear in unabridged dictionaries but are useless in determining the defining attributes (Markle, 1975). In arriving at the defining attributes of most concepts, the concept

analyzer (if not expert in the particular subject matter) uses authoritative printed materials and also may seek the assistance of subject-matter experts.

SPECIFYING THE DEFINING ATTRIBUTES

The concept analyzer specifies the defining attributes of the concept in order to identify sets of teaching examples and non-examples (Markle & Tiemann, 1969) and also to teach students an algorithmic strategy for evaluating instances as examples and non-examples of the concept, as will be explained later.

Those attributes which are present in every example of a concept, and therefore also distinguish the concept examples from examples of all other concepts, are called the defining attributes of the concept. Establishing the defining attributes of the concept and arriving at a definition of the word representing the concept proceed simultaneously during a concept analysis.

The following rationale was adopted for determining defining attributes: the defining attributes of a process-concept are the more discrete operations that are used in performing the more global operation, and also the prerequisite prior operation(s). As can be seen in Figure 1, there are no processes designated as prerequisite to observing scientifically, therefore, the defining attributes of this process-concept are the more discrete operations which are involved, namely: (1) using one or more of the senses, (2) examining critically, and (3) recording data precisely.

SPECIFYING THE VARIABLE ATTRIBUTES

The variable attributes of the concept are identified to facilitate the later selection of examples and nonexamples. Examples of the same concept vary widely on their nondefining attributes. For example, reptiles are of many different colors and sizes; fish also vary in the same colors and are of various sizes. The attributes which members of the reptile class and members of the fish class have in common and which therefore may hinder persons in discriminating between the members of the two classes are called variable attributes. In most previous reports, starting with Bruner, Goodnow, and Austin (1956), these variable attributes have been called irrelevant attributes.

The first rule for identifying variable attributes is to identify those that are common to the concepts that are coordinate to the target concept. It is these attributes that are present in both the examples and nonexamples of a particular concept and that often lead to errors in classification. The second rule is to identify attributes that may be present in both the target concept and either its supraordinate or subordinate concepts. With concepts that are not part of a taxonomy, one identifies the variable attributes intuitively, selecting those that learners may incorrectly consider as defining attributes of the target concept.

The rationale for specifying variable attributes was to select some of the more common attributes that vary among examples of the

process, and to include attributes that are present in both examples and nonexamples of a particular process-concept. Often, the variable attributes of a particular process-concept are the same attributes which are variable for closely associated or coordinate process-concepts or include the attributes of any of the other operations with which the particular process might be easily confused.

Some of the variable attributes for observing scientifically are: (1) the objects or events being observed, (2) the sense or senses being used, (3) the place or situation in which objects or events are observed, (4) the method of recording data.

SELECTING ILLUSTRATIVE EXAMPLES AND NONEXAMPLES

Examples and nonexamples of the concept are needed in teaching the concept and in assessing students' learning of the concept. At least one set of examples and nonexamples is identified during the concept analysis in such a way as to ensure that errors of under-generalization, overgeneralization, and misconception by the learner will be avoided (Markle & Tiemann, 1969; Markle, 1975). When several concepts of the same taxonomy are taught in a series of lessons, the nonexamples of any one concept are in reality examples of other concepts of the taxonomy. Using examples of related concepts for nonexamples of the target concept permits the defining attributes to be excluded meaningfully from each nonexample (thereby preventing over-

generalization) and the variable attributes to be included meaningfully in both the examples and nonexamples (thereby preventing undergeneralization).

One cannot deal with examples and nonexamples of concepts in a hierarchy as systematically as in the taxonomy, since there often are neither coordinate nor supraordinate concepts. An intuitive approach is required and the emphasis is placed more on the selection of examples and nonexamples than on matching the defining and the variable attributes. A few examples and nonexamples of observing scientifically follow:

1. Example of observing scientifically (all defining attributes included and explicit):

   Bill looked at a marshmallow carefully, felt it, tasted it, and smelled it. Then he put it over the flame of a Bunsen burner and watched as it turned from white to black. He smelled it as it burned. After it cooled, he felt it and noticed that it felt crisp. He tasted it and thought that it tasted like charcoal. He recorded these things in his report book.

2. Example of observing scientifically (all defining attributes included and explicit):

   Cindy asked Cecil to observe the liquid in two glasses scientifically. The liquid in both glasses was clear. Cecil's job was to decide if the same liquid was in both glasses.

Cecil smelled the liquid in the two glasses, one at a time. First he smelled the liquid in Glass A. Then he smelled the liquid in Glass B. "No, Cindy," he said, "the liquid in the two glasses is not the same, even though they do look alike. The liquid in Glass B is alcohol. I can tell by the smell." Cecil wrote on the chart, "The liquids are different. Glass B is filled with alcohol."

3. Example of observing scientifically (all defining attributes included and explicit):

Cecil's assignment was to observe popcorn scientifically. He found a popcorn popper with a glass lid. He put in the oil, heated it, and then added the popcorn to pop. He watched carefully, writing down how long it took the corn to start popping. He listened to the sound it made and recorded the sound with his tape recorder. When it had stopped popping, he felt some with his fingers. It was smooth on the outside and crisp on the inside. He tasted it and noticed that it did not taste salty like the popcorn at the movie theater. He wrote all of this information accurately in his notebook so that he could write his report later.

4. Nonexample of observing scientifically (one or more defining attributes not included):

Cecil saw the mailman deliver a box to the principal. Without looking at the label or inside the box, Cecil thought to himself, "The principal said he was going to order a new microscope for the school." Cecil saw his friend, Jim, and told him that he saw the new microscope arrive.

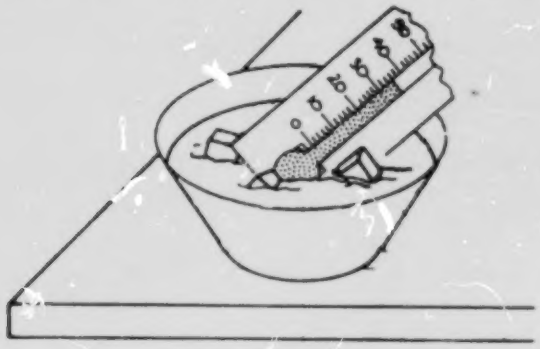
5. Nonexample of observing scientifically (one or more defining attributes not included):

Cindy asked Cecil to observe the liquid in two glasses scientifically. The liquid in both glasses was clear. Cecil's job was to decide if the same liquid was in both glasses.

Cecil stood about five feet away from the two glasses. He quickly glanced at the liquids in the glasses. "Those glasses look like they are filled with the same liquid. They must both be filled with water." Cecil wrote on the chart, "The liquids in the two glasses are clear."

6. Nonexample of observing scientifically (the defining attributes are actually those of another process-concept, namely measuring):

Charlie wanted to find the temperature of the ice water in a bowl. He put a thermometer into the bowl of ice water. He looked carefully at the thermometer and said: "The temperature of the ice water is 36 degrees Fahrenheit."



IDENTIFYING ILLUSTRATIVE PRINCIPLES

One of the several ways in which concepts are useful to an individual is in understanding principles that incorporate the concepts. Understanding principles which involve cause-and-effect or correlational relationships among concepts, in turn, makes it possible to explain many events and, in some cases, to predict and to control (Bruner, 1960; Klausmeier,Ghatala, & Frayer, 1974). Understanding principles facilitates the solution of problems. It is useful, therefore, to identify illustrative principles of which the target concept is a part to promote transfer of concept learning to the understanding of principles.

The rationale for specifying principles was primarily as follows: (1) use relationships (cause and effect, correlational, probability, or axiomatic) between the target process-concept and other process-

concepts in the proposed hierarchy (see Figure 1), (2) use relationships between the defining attributes related to the target process-concept, or (3) use relationships between the target process-concept and another related concept.

Illustrative principles involving the process-concept observing scientifically follow:

1. Observing objects and events is prerequisite for drawing inferences regarding them.
2. Using more than one of the senses in observing objects and events increases the probability of gaining more precise information.
3. Quantitative observation permits the drawing of more precise inferences than does qualitative observation.

Examination of the principles indicates that each one expresses a relationship between the target concept and another one in the taxonomy or hierarchy, between the target concept and one or more of its defining attributes, or between the target concept and a less closely related concept. There appear to be no rules for arriving at a set of illustrative principles. However, once a principle is identified, correct applications and misapplications can be identified and used in teaching the principle (Feldman, 1974; Katz, 1975).

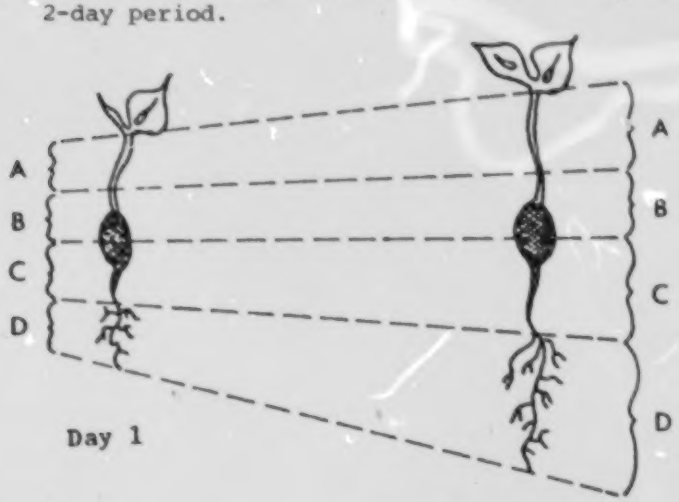
FORMULATING ILLUSTRATIVE PROBLEM-SOLVING EXERCISES

As part of a concept analysis, problem-solving exercises are formulated, the solutions of which presumably are facilitated by under-

standing the target concept and applying knowledge of a principle or a combination of principles. No attempt is made to make the problem-solving exercises of equal difficulty. On the contrary, a range of difficulty is preferable in the analysis so that additional examples of an appropriate level of difficulty can later be prepared for a particular target population of students.

A few problem-solving exercises for <u>observing scientifically</u> follow:

1. The drawing below shows the growth of a plant over a 2-day period.



Observe the growth of the plant scientifically.
Which part has grown the most?

a. Part A
b. Part B
c. Part C
(d.) Part D

2. What would you do to observe whether some parts of a plant grow more quickly than other parts?

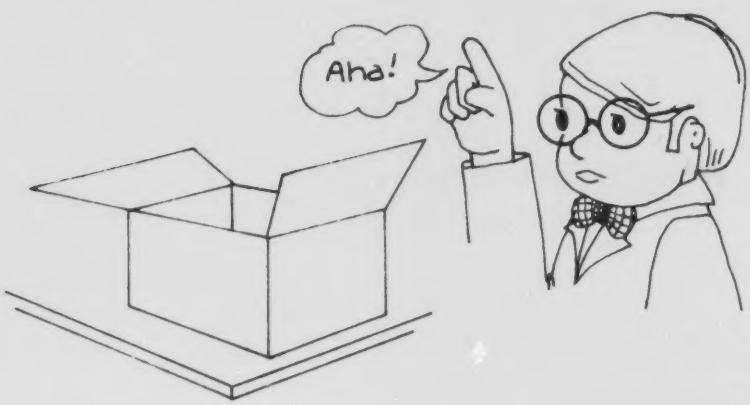
   a. Weigh the plant now, and again at the end of 1 week.

   b. Measure the height of the plant now, and again at the end of 1 week.

   c. Count the number of leaves and roots which the plant has.

   (d.) Put several marks on different plant parts, then place the plant beside a meter stick and observe daily.

3. Cindy told Cecil to observe scientifically what was in a box in the next room. Cecil had never seen the box before. It had just come in the mail that day. Here are two endings to this story.



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Ending 1

Cecil was in a hurry. He did not want to bother to go into the next room to look at the box and what was in it. "Hmm," he said to himself. "Cindy was going to order a new microscope." Without going to look at the box, Cecil wrote in his report book, "I have observed scientifically that there is a microscope inside the box."

Ending 2

Cecil went into the next room and looked at the large box on the table. He picked up the box, shook it, and listened to the rattling sound. Then he opened the box and felt inside carefully. He touched something that was metal and he felt its shape. It had the shape of a horseshoe. Then he looked inside and saw what he had felt. It looked like a magnet. He took it out and tried it on some paper clips. He found that it was a magnet. He measured it and then wrote in his report book, "I have scientifically observed the object inside the box. It is a magnet. It is gray metal with red ends and is five inches high and three inches wide."

In which ending did Cecil observe scientifically?

a. Ending 1

(b.) Ending 2

DEVELOPING A VOCABULARY LIST

The rule for generating a vocabulary list as part of a concept analysis is to include the name of the concept and the key terms of the defining attributes. The extent to which the terms will be used in teaching a particular concept varies greatly according to the level of attainment desired. None of it may be used at the concrete level; all of it must be used at the formal level. Students' knowing the name of the concept and the names of its defining attributes correlates positively and high with the level of concept attainment and also the uses of concepts (Klausmeier, Sipple, & Allen, 1974a, 1974b).

The vocabulary list for observing scientifically follows:

to observe (observing)
to record
to measure
to examine
senses
scientist
observer
information
experiment
accurately
precisely
critically
scientifically

NINE SCIENCE PROCESS-CONCEPT ANALYSES

Conducting a concept analysis is necessary for preparing instructional materials to teach concepts, and is prerequisite to the writing

of lessons and tests. The following steps are involved in the concept analysis procedure: (1) outlining the hierarchy or the taxonomy of which the target concept is a part, (2) stating a definition of the concept in terms of its defining attributes, (3) specifying the defining attributes and some of the variable attributes of the concept, (4) providing illustrative examples and nonexamples of the concept, (5) identifying some principles in which the concept is incorporated, (6) formulating problem-solving exercises involving use of the concept, and (7) developing a list of the key vocabulary associated with the concept.

Analyses of eight basic and one integrated process-concepts of elementary science comprise the remaining portion of this paper.

ANALYSIS OF OBSERVING SCIENTIFICALLY

A. TECHNICAL DEFINITION:

Observing scientifically--Using one or more of the senses in critically examining objects or events and precisely recording data about those objects or events.

COMMON USAGE DEFINITION:

Observing scientifically--Using one or more of the senses to examine something carefully and to accurately record information about what is observed.

B. DEFINING ATTRIBUTES:

(1) Using one or more of the senses

(2) Examining critically

(3) Recording data precisely

C. VARIABLE ATTRIBUTES:

(1) The objects or events being observed

(2) The sense or senses being used

(3) The place or situation in which objects or events are being observed

(4) The method of recording data

D. EXAMPLES OF OBSERVING SCIENTIFICALLY:

(1) A boy was asked to scientifically observe a ten day old bean plant; then he looked at the plant carefully, felt its leaves, and measured it with a ruler. In his report book, the student wrote, "The ten day old plant is 7.5 cm high. It has four leaves that are light green in color, smooth, and shiny. It has a very straight stem."

(2) A girl wanted to observe what happened to a marshmallow when it was placed over a lighted bunsen burner. First she looked at the marshmallow carefully, felt it, tasted it, and smelled it. Then she put it into the flame and watched as the marshmallow turned from white to black. She smelled it as it burned. After it cooled, she felt it and noticed that it felt crisp. She tasted it and thought that it tasted like charcoal. The girl wrote all of these things accurately in her report book.

(3) One day, Cecil and Cindy were watching the seals at the zoo. They knew that it was almost feeding time. "Let's

observe how the seals respond to the sight of their food," said Cecil. They watched and listened carefully as the zookeeper brought the fish for the seals. As soon as one seal saw the fish, it clapped its flippers and barked loudly. Cecil used a tape recorder to record the barking. Cindy recorded this information accurately in her notebook: "The stimulus for the seal was the sight of the fish. The seal's responses were clapping and barking."

E. NONEXAMPLES OF OBSERVING SCIENTIFICALLY:

(1) This is an instance in which the senses are not used and careful examination is not performed:

Cindy told Cecil to observe scientifically what was in a box in the next room. Cecil had never seen the box before because it had just arrived in the mail that day. Without bothering to go into the next room and open the box, he thought to himself, "Cindy was going to order a new microscope." Then instead of observing scienf-ically he jumped to the conclusion that the box contained a new microscope.

(2) This is an instance in which information about what was observed was not recorded accurately:

One day at the zoo, Cindy and Cecil watched a trained bear. "Let's observe how the bear responds to stimuli," said Cecil. They watched and listened carefully as the

trainer snapped his whip above the bear's head. At the sound of the whip, the bear sat up on its hind legs. "The stimulus was the sound of the whip," said Cecil. "The bear's response was sitting up," said Cindy. But they were so interested in watching the bear that they forgot to record this information.

(3) This is an instance in which something was not examined carefully:

Cecil was given an assignment. He was told to observe three cubes of butter on an electric hot plate and to record on a graph which one melted first. The cubes of butter were the same size. Cecil did not know it, but one cube was frozen butter, one cube was cold butter from the refrigerator, and one cube was butter at room temperature. He looked at the three cubes of butter and saw that they were yellow and all the same size. Then he turned to talk to a friend about the football game last Saturday. While he was talking, the room temperature butter melted first, in 1-1/2 minutes. The cold butter melted next, in 3 minutes. The frozen butter melted last, in 4-1/2 minutes. When Cecil looked back 5 minutes later, all three cubes had melted. Cecil recorded in his notebook that he had observed scientifically that all three cubes of butter had melted at the same time. They had all taken five minutes to melt.

F. STATEMENT OF PRINCIPLES:

(1) In general, the more senses that are used in making scientific observations, the greater is the probability of gaining useful information.

(2) Quantitative observations permit more precise inferences and predictions than do qualitative observations.

(3) Observing scientifically is not the same as observing casually.

(4) Scientific observations are essential for drawing inferences, making predictions, and formulating hypotheses regarding natural phenomena.

G. SAMPLE PROBLEMS:

(1) Read the following story:

On his way home from school, Bob heard a siren. "A fire engine is coming this way," he thought. He looked in the direction of the sound to see if there was any smoke. The sound of the siren got louder. Suddenly, an ambulance turned the corner near him and went down Elm Street toward the hospital. "It's not a fire," thought Bob. "There's been an accident."

Which one of the following is an <u>observation</u> which Bob made?

a. He saw a fire
b. He saw an accident.
c. He heard a siren.
d. He thought a fire engine was coming.

(2) An experiment was performed using the 3 things shown below.

feather

crumpled paper

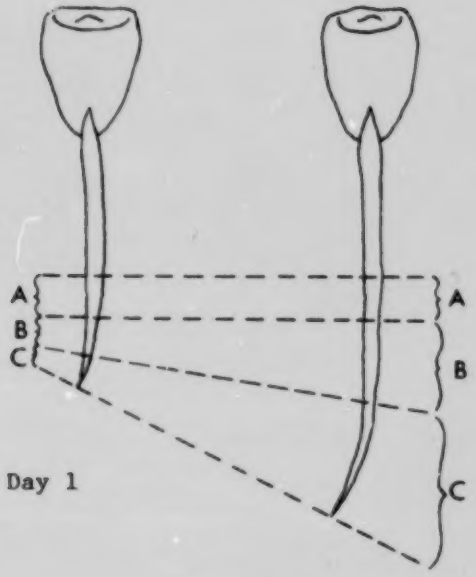
ping-pong ball

The feather, the crumpled paper, and the ping-pong ball were all dropped at the same time from the top of a tall building. The ping-pong ball hit the ground first.

Why did this happen? What can you observe about the surface area of the 3 objects?

a. The 3 objects have the same surface area.
b. The ping-pong ball has the least surface area.
c. The ping-pong ball has the most surface area.
d. The feather has the least surface area.

(3) The drawing below shows the growth of a root from Day 1 to Day 2.



Observe scientifically.

Where has the root grown the most?

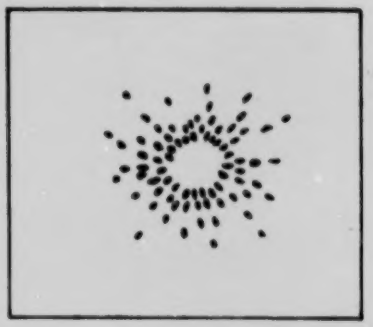
a. in Section A
b. in Section B
c. in Section C

Observe scientifically.

Where has the root grown the least?

a. in Section A
b. in Section B
c. in Section C

(4) Some iron filings were scattered on a sheet of paper. Then the sheet was placed over a metal disc. The disc created a pattern in the iron filings like this:



Scientifically observe the pattern of the iron filings. You could say that the disc

a. has gravity
b. has a magnetic field
c. has no magnetism
d. has tension

(5) Look at the 2 pictures below:

1

2

What scientific observations can you make?

_____

_____

_____

30

(6) Look at the picture below:

What scientific observations can you make?

_____

_____

_____

H. KEY VOCABULARY:

to observe (observing)

to record

to measure

to examine

senses

scientist

observer

information

experiment

accurately

precisely

critically

scientifically

ANALYSIS OF INFERRING

A. TECHNICAL DEFINITION:

Inferring--Relating what one already knows to an observed object(s) or event(s) and drawing a conclusion that explains the observation.

COMMON USAGE DEFINITION:

Inferring--Relating a scientific observation to something which is known, and drawing a conclusion about what was observed.

B. DEFINING ATTRIBUTES:

(1) Relating a scientific observation to something which is known

(2) Drawing a conclusion about what was observed

C. VARIABLE ATTRIBUTES:

(1) The object(s) or event(s) involved

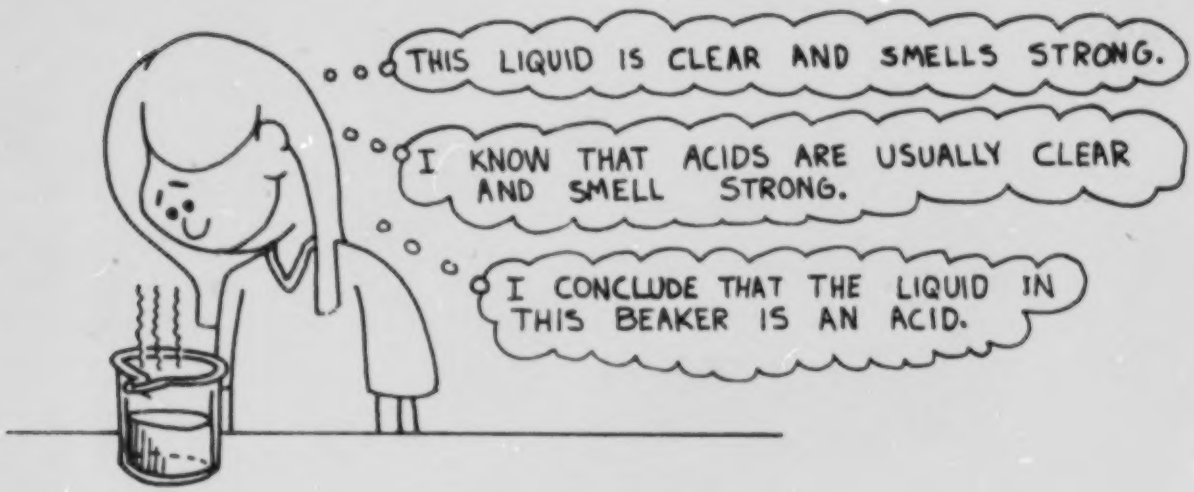
(2) The knowledge that is used as a basis for the inference

(3) The kind of relationship inferred (probability, cause-and-effect, correlational, axiomatic)

EXAMPLES OF INFERRING:

(1) Two children saw a footprint while they were walking on a forest trail. One of the children had observed many wild ducks in the area on past occasions. After examining the webbed footprint, the child inferred that the track was left by one of the wild ducks.

(2) Look at the cartoon below.


THIS LIQUID IS CLEAR AND SMELLS STRONG.
I KNOW THAT ACIDS ARE USUALLY CLEAR AND SMELL STRONG.
I CONCLUDE THAT THE LIQUID IN THIS BEAKER IS AN ACID.

When the girl concluded that the liquid in the beaker was an acid, she was inferring.

(3) Karen was fishing with her sister when she felt a strong tug on her line. Then the line snapped. Karen told her sister, "I know that a large fish can break this line. I think that a very large fish broke my line."

(4) Joe baked a cake. The cake did not rise. Joe knew that baking powder makes cakes rise. He concluded that he had left the baking powder out of his cake.

E. NON-EXAMPLES OF INFERRING:

(1) This is an instance in which a scientific observation is related to something that is known but no conclusion is drawn about the observation.

Mary saw some duck tracks on her lawn. She said, "I remember seeing ducks here before. I know that some ducks flew over here yesterday."

(2) This is an instance in which a conclusion is not based on a scientific observation.

Betty showed Tom an unopened box. Tom did not scientifically observe the box, but said:

(3) This is an example of another concept (Classifying) which may be used as a nonexample of Inferring to prevent over-generalization.

Chris baked three dozen cookies. They were not all the same kind: one dozen was chocolate chip, one dozen was oatmeal, and one dozen was sugar cookies. Chris put all the chocolate chip cookies into one cookie jar, all the oatmeal cookies into another jar, and all the sugar cookies into a third jar.

F. STATEMENT OF PRINCIPLES:

(1) Making more accurate and reliable scientific observations permits the drawing of more accurate and reliable inferences.

34

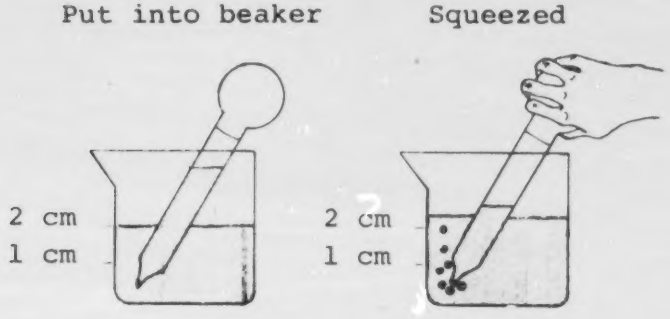
(2) Inferences based upon two or more scientific observations are more reliable than those based upon a single observation.

(3) Quantitative observations allow more precision and accuracy in drawing inferences than do qualitative observations.

(4) Scientific observing and inferring are essential for predicting the outcomes of scientific events.

G. SAMPLE PROBLEMS:

(1) A kitchen baster full of water was put into a beaker of water and squeezed.



What inference can you make from this experiment?

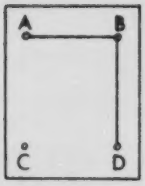
a. The water in the baster was displaced by air.
b. The water level in the baster went down.
c. The air in the baster was displaced by water.
d. The water level in the beaker went down when the baster was squeezed.

(2) The chart below shows the open and closed circuits in a hidden circuit board.

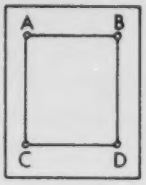
Pair	A-B	A-C	A-D	B-C	B-D	C-D
Closed	X		X		X	
Open		X		X		X

Which of the following connections could <u>not</u> be inferred?

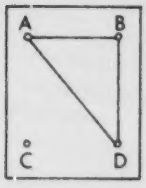
a.



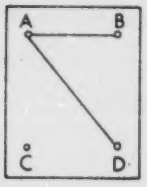
b.



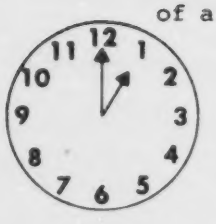
c.

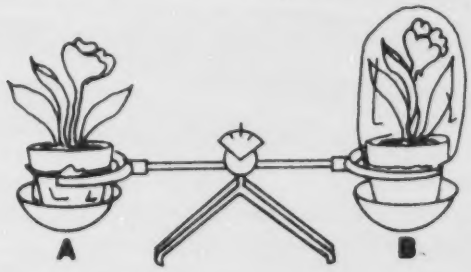


d.

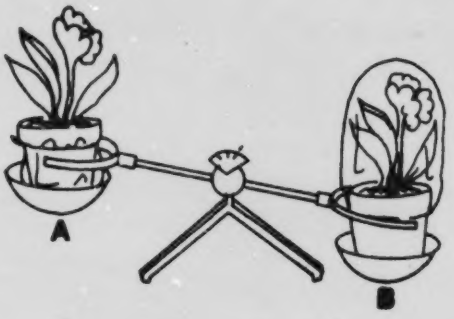


(3) Look at the drawing below. Two plants of the same size were placed on an equal-arm balance at 1:00 p.m. A plastic bag was sealed around Plant B. Plant A was placed on top of a plastic bag. At 1:00 Plant A exactly balanced Plant B.





Two hours later, however, Plant A weighed less than Plant B.



From this observation, you could infer that water was lost from Plant A but

a. Plant B lost water faster
b. the plastic bag did not let moisture from Plant B escape
c. the plastic bag did not let Plant B get any sunlight
d. Plant B dried out more than Plant A

(4) Look at the drawing below.

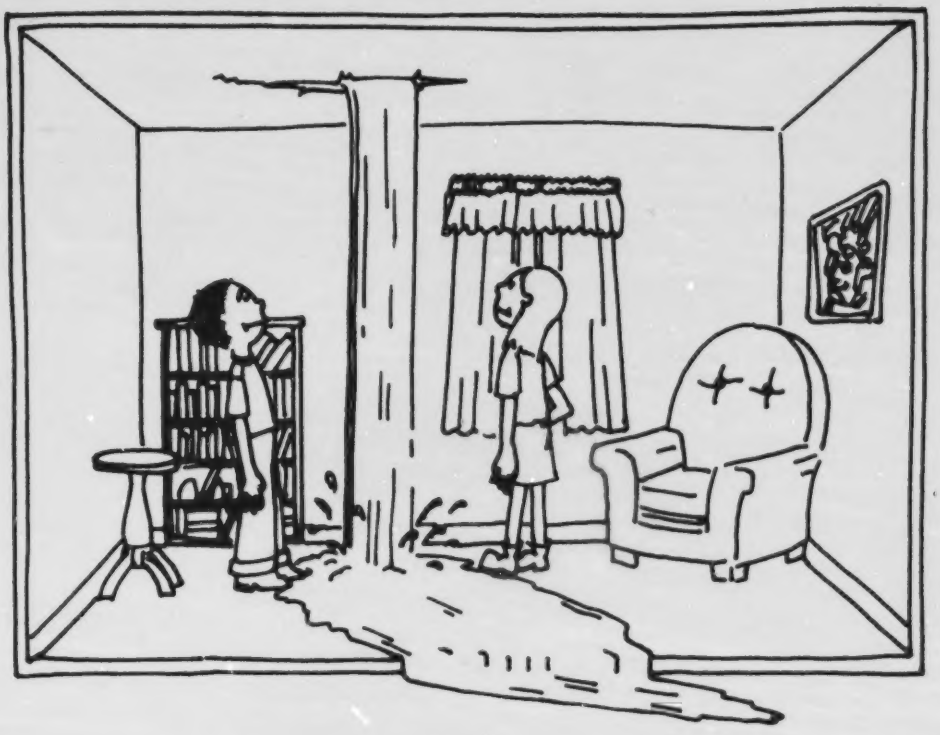
What is a reasonable <u>inference</u> you might make?

_____

_____

_____

(5) Look at the picture below:



Make an inference about what happened in the picture above.

_____

_____

_____

H. KEY VOCABULARY:

to infer (inferring)

to relate

to observe scientifically

to conclude

conclusion

relationship

inference

observation

H. KEY VOCABULARY (continued):

accurately

scientifically

ANALYSIS OF PREDICTING

A. TECHNICAL DEFINITION:

Predicting--Using a previous inference or inferences to forecast what will occur under given or assumed conditions.

COMMON USAGE DEFINITION:

Predicting--Using an inference to forecast what will happen.

B. DEFINING ATTRIBUTES:

(1) Using an inference or inferences

(2) Forecasting what will occur

C. VARIABLE ATTRIBUTES:

(1) The objects or events involved

(2) The nature of the forecast (oral, written)

(3) How far in advance of the outcome a prediction is made

(4) How many inferences or observations the prediction is based upon

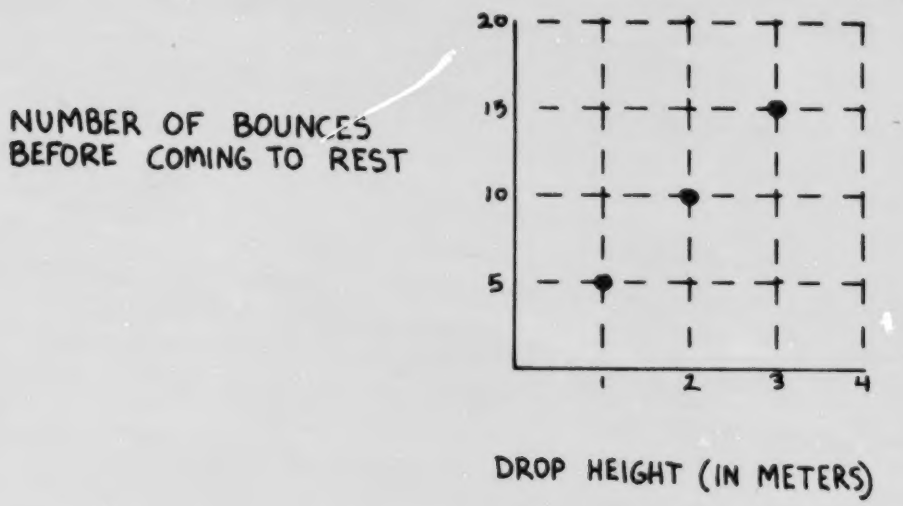
D. EXAMPLES OF PREDICTING:

(1) Jim looked out the window and saw dark gray clouds in the west. He inferred that these were the same type of clouds which always bring bad weather. Jim told his sister, "Let's put our bikes in the garage. It is going to rain very soon."

(2) There were four squirrels living in Mary's back yard. Mary inferred that the squirrels ate nuts, so she put some walnuts on the lawn. Mary said, "These nuts will be gone soon."

(3) Janet took a survey of her fourth-grade class. She found that 15 people liked chocolate ice cream, 9 liked vanilla, and 4 liked strawberry. Janet inferred that chocolate was the favorite flavor of her class. She told the principal, "Most of the children in our school will want chocolate ice cream at the school picnic."

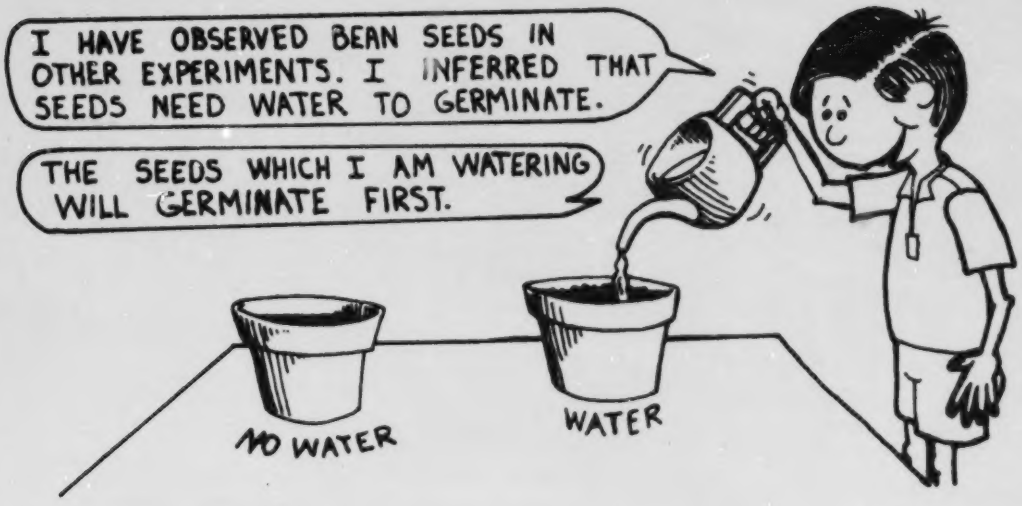
(4) Sandy did an experiment with a bouncing golf ball. She dropped the ball from heights of 1, 2, and 3 meters, and got these results:



Sandy concluded that "the greater the height from which a ball is dropped, the more times it will bounce before coming to rest." She looked at her results and said,

"If I were to drop the golf ball from a height of 4 meters, it would bounce 20 times."

(5) Look at the cartoon below.


I HAVE OBSERVED BEAN SEEDS IN OTHER EXPERIMENTS. I INFERRED THAT SEEDS NEED WATER TO GERMINATE.
THE SEEDS WHICH I AM WATERING WILL GERMINATE FIRST.
NO WATER
WATER

Robert made a prediction when he said, "The seeds that I am watering will germinate first." He used an inference to tell what would happen.

E. NONEXAMPLES OF PREDICTING:

(1) This is an instance in which an inference is not followed by a forecast of what will happen.

Cindy looked at some tracks in the snow.

Cindy did not make a prediction. She inferred that the tracks were made by rabbits, but she did not forecast what would happen. When Cindy said, "I am sure that rabbits were here this morning," she told about something which had already happened, not something which would happen.

(2) This is an instance in which an inference is not followed by a forecast of what will happen.

Sue did an experiment with rolling cylinders. She found that solid cylinders roll faster down an incline than hollow cylinders. Sue concluded that a solid object rolls faster down an incline than a hollow object.

(3) This is an instance in which a forecast is not based on a previous inference.

Early one morning, Tom looked out his bedroom window at the wet grass.

He forecasted what would happen when he said, "The leaves will soon be falling from the trees," but Tom did not use an inference to forecase what would happen.

(4) This is an example of another concept (observing scientifically) which may be used as a nonexample of Predicting to prevent overgeneralization.

Cecil was asked to scientifically observe a puppy playing with a rubber ball. Cecil watched and listened carefully. He examined carefully how the puppy played with the ball. He accurately wrote down everything that he saw and heard. When the puppy bit the ball, the ball sent, "Squeak!" The puppy jumped back when he heard this. Cecil wrote down, "The squeak

of the ball made the puppy jump back. The squeak of the ball was the stimulus. The response of the puppy was jumping back."

F. STATEMENT OF PRINCIPLES:

(1) Making increasingly accurate scientific observations and inferences permits the making of more accurate predictions.

(2) Making a larger number of scientific observations and inferences permits the making of more accurate predictions.

(3) Scientific observing and inferring are essential to predicting.

(4) Expressing previous scientific observation or past experiences in quantitative terms permits more precision and accuracy in predicting than does expressing them in strictly qualitative terms.

G. SAMPLE PROBLEMS:

(1) Cindy did an experiment with two sheets of paper. She crumpled one sheet into a ball. The other sheet was open and flat. Using the inference that OBJECTS WITH LESS AIR RESISTANCE FALL FASTER THAN OBJECTS WITH GREATER RESISTANCE, make a prediction about which sheet of paper will hit the floor first:

_____

_____

_____

(2) Look at the picture above. A glass jar has been put over a burning candle. Using the inference that FIRE MUST HAVE AIR TO BURN, make a prediction about the burning candle:

_____

_____

_____

(3) What would be the <u>best</u> way to find the games children would like to play at a class party?

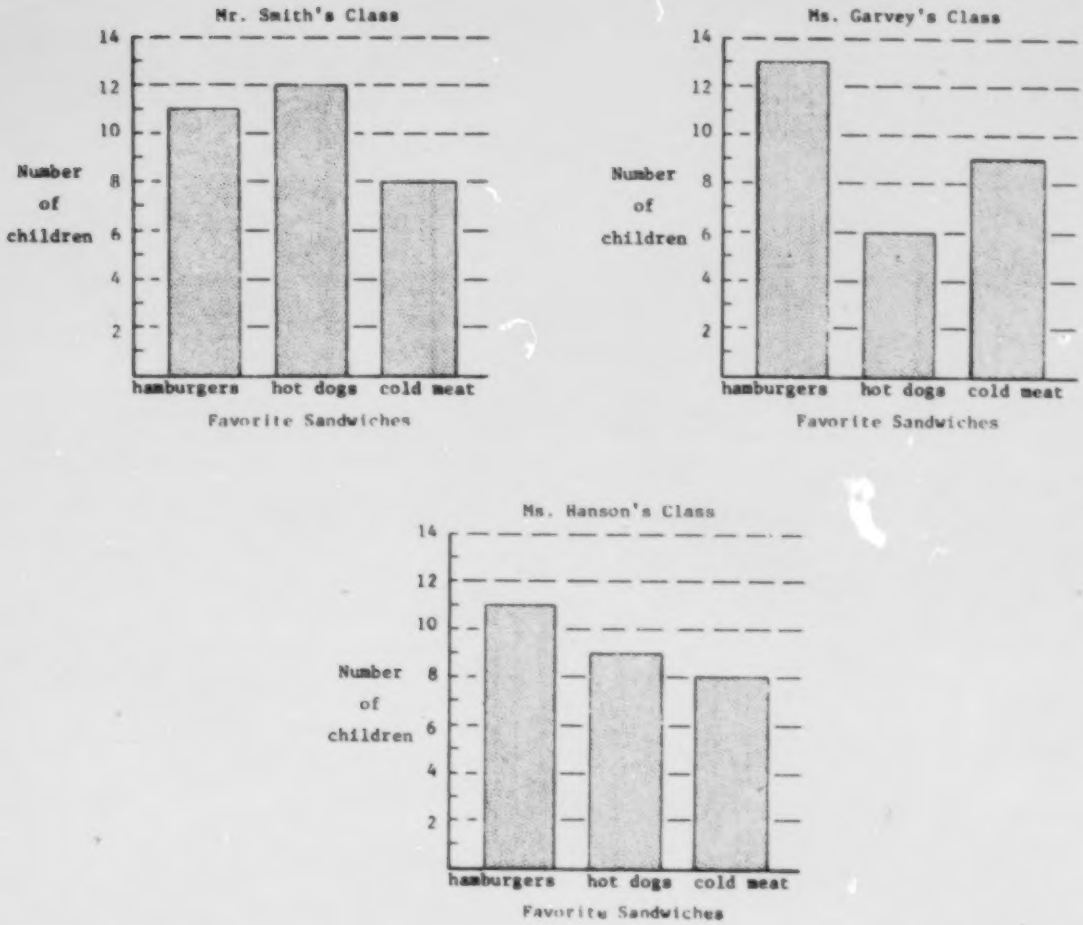
a. Take a survey of teachers to find what games children like to play.

b. Take a survey of the children in the class to find what their favorite games are.

c. Ask the principal what games are fun to play.

d. Remember the games you like to play and list them.

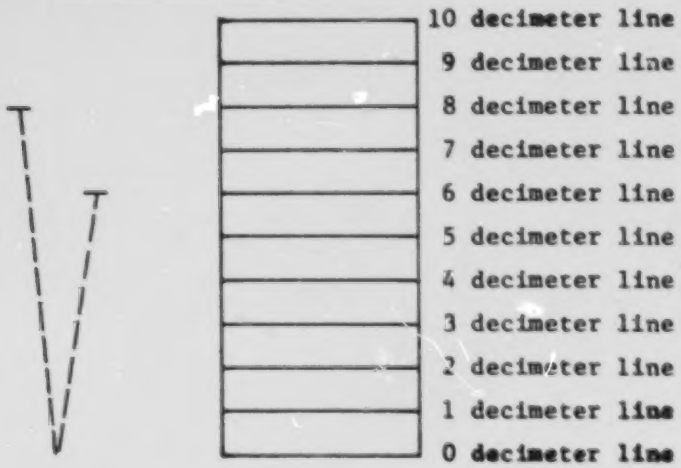
(4) Look at the 3 graphs below. Each graph shows the favorite sandwiches of a different fourth-grade class in the same school.



Use the 3 graphs to predict the favorite sandwich of another fourth-grade class in the same school. What would your prediction be?

a. hamburger
b. cold meat
c. hot dog

(5) Below is a chart used to measure how high a ball bounces. If a golf ball is dropped from line 8, it hits the floor and bounces back to line 6.



If you drop the golf ball from a height of 10 decimeters, how high will it bounce?

a. to line 6
b. higher than line 6
c. lower than line 6

H. KEY VOCABULARY:

to predict

to observe scientifically

to infer

to forecast

outcome

previous

prediction

observation

inference

H. KEY VOCABULARY (continued):

interpolation

extrapolation

graph

ANALYSIS OF CLASSIFYING

A. TECHNICAL DEFINITION:

Classifying--Forming classes or groups by discriminating certain features of a set of object or events and generalizing that all things having one or more common attributes belong together in the same class or group.

COMMON USAGE DEFINITION:

Classifying--Identifying how things are different, identifying all those things which are alike in some way, and grouping together those things which are alike in some way.

B. DEFINING ATTRIBUTES:

(1) Identifying how things are different

(2) Identifying all those things which are alike in some way

(3) Grouping together all those things which are alike in some way

C. VARIABLE ATTRIBUTES:

(1) The kinds of things being classified

(2) The number of things being classified

(3) The number of groups or classes that are formed

(4) The perceptibility of the attributes

D. EXAMPLES OF CLASSIFYING:

(1) Don emptied his bank. He saw that the coins were different: some were pennies, some were nickels, and some were dimes. He put all of the pennies into one pile, all of the nickels into another pile, and all of the dimes into a third pile.

(2) Susie cleaned out the garage. She noticed that the tools were mixed up. Susie thought, "Some of these are gardening tools and some are wood-working tools." Then she put the hoe and the rake on the north wall and the saw and the hammer on the east wall.

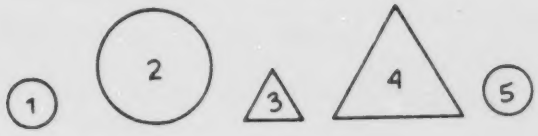
(3) Paul looked at these things:

First he said, "These things are different: some have four legs and some have no legs."

Next Paul said, "The cat, the dog, and the cow are alike in a certain way: they have four legs. The snake and the fish are alike in a certain way: they have no legs."

Then Paul put the things into these two groups:

(4) Sue looked at five figures:



First Sue said:

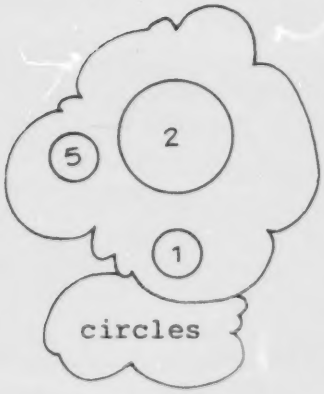
These things are different: some are circles and some are triangles.

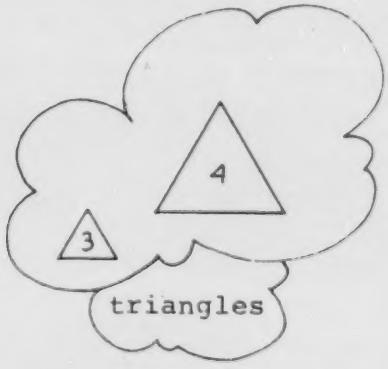
Next she said:

1, 2, and 5 are alike in a certain way: they are circles.

3 and 4 are alike in a certain way: they are triangles.

Then Sue grouped the things into these two groups:





E. NONEXAMPLES OF CLASSIFYING:

(1) This is an instance in which a person did not group together those things which are alike in some way

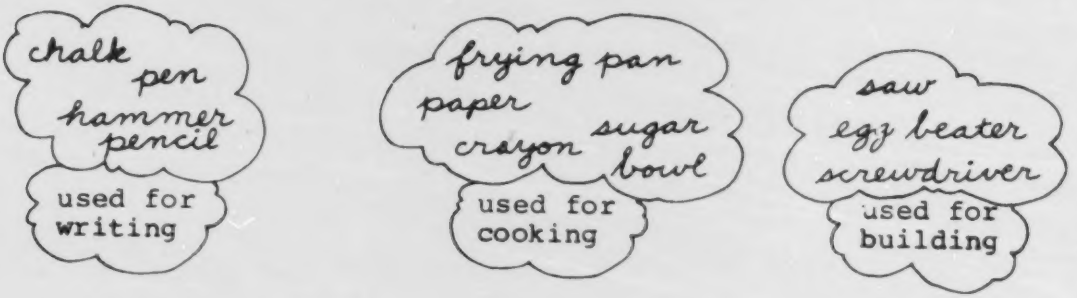
Larry looked at these things:

PEN	HAMMER	SCREWDRIVER
CHALK	BOWL	CRAYON
FRYING PAN	PAPER	EGG BEATER
SAW	SUGAR	PENCIL

First he said, "These things are different: some are used for writing, some are used for cooking, and some are used for building."

Next Larry said, "Pen, chalk, paper, crayon, and pencil are alike in a certain way: they are used for writing. Frying pan, bowl, sugar, and egg beater are alike in a certain way: they are used for cooking. Saw, hammer, and screwdriver are alike in a certain way: they are used for building."

Then Larry put the things into three groups:



(2) This is an instance in which a person did not identify and group together all those things which are alike in some way.

Mike looked at these four things:

First he said, "These plants are different: some are tall and some are short."

Next Mike put the things into these two groups:

(3) This is an instance in which a person did not group together those things which are alike in some way.

Karen wrote these words on the blackboard:

BED	JUMP	RUN
CLIMB	SWIM	CHAIR
STONE	CAT	DRIVE

First she said, "These words are different: some are action words, and some are name words."

Next Karen said, "Climb and swim are alike in a certain way: they are action words. Jump and cat are alike in a certain way: they are name words."

(4) This is an example of another concept (Observing scientifically) which may be used as a nonexample of Classifying to prevent overgeneralization.

Tom walked into the garage and found these things on his father's workbench:

He examined the five objects carefully.

F. STATEMENT OF PRINCIPLES:

(1) The same objects, events, processes, or ideas may be put into more than one class, depending upon which feature(s) are discriminated and generalized to be in common.

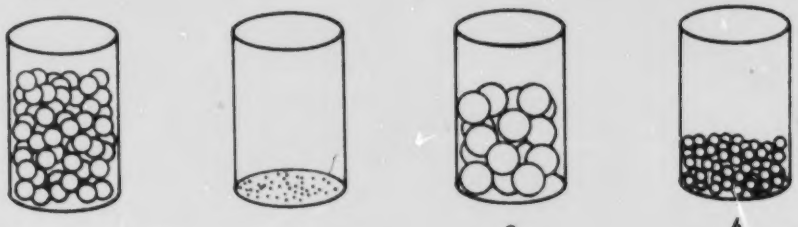
(2) In most cases, the greater the number of observable or inferable differences between classes or groups, the more restricted the class membership and the more specific the classification.

(3) Observing scientifically, generalizing and discriminating are essential to classifying.

(4) If a number of things are classified into two or more distinct groups, then the members of a particular group may be observed or inferred to be different from the members of other groups in at least one way.

G. SAMPLE PROBLEMS:

(1) Look at the volume taken up by the things in each container below.



Order the contents of the containers according to volume from smallest to largest.

a. 2, 4, 3, 1
b. 1, 3, 4, 2
c. 2, 4, 1, 3
d. 1, 2, 3, 4

(2) Put an X next to the stories in which someone is classifying.

____George's mother asked him to sort the socks. George saw that some were his socks and some were his brother's. He put all of the socks away. The next morning his brother said to George, "What is this pair of your socks doing in my drawer?"

____Chris baked 3 dozen cookies. They were not all the same kind: 1 dozen was chocolate chip, 1 dozen was oatmeal, and 1 dozen was sugar cookies. Chris put all the chocolate chip cookies into one cookie jar, all the oatmeal cookies into another jar, and all the sugar cookies into a third jar.

_____John was asked to arrange the books in the library. He saw that the books were different in size: some were tall and others were short. John put all the tall books on the top shelf and all the short books on the bottom shelf.

_____When Mary cleaned the gym storeroom, she put all the equipment into a barrel. The coach was angry with Mary because she put the football and baseball equipment into the same barrel.

(3) Classify the shapes below in two different ways:

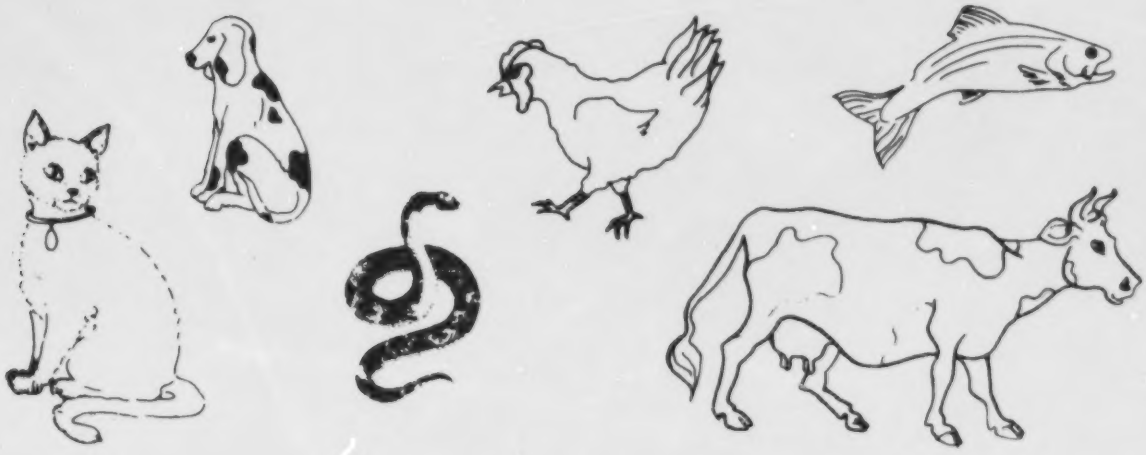
How could you group these figures in one way?

How are the groups different?

How could you group these figures in a different way?

How are the groups different?

(4) Look at the pictures below. Tell how you could classify these things in <u>three</u> different ways.



_____

_____

_____

_____

H. KEY VOCABULARY:

to classify

to observe scientifically

to group

to sort

to generalize

to discriminate

to identify

different

alike

collection

classification

ANALYSIS OF MEASURING SCIENTIFICALLY

A. TECHNICAL DEFINITION:

Measuring scientifically--Choosing an appropriate standard measuring instrument and assigning an accurate and precise numerical value to some dimension of a measurable object.

COMMON USAGE DEFINITION:

Measuring scientifically--Using a standard measuring tool that is correct for what is being measured, and finding the correct number of standard units that something measures.

B. DEFINING ATTRIBUTES:

(1) Using a standard measuring tool that is correct for what is being measured

(2) Finding the correct number of standard units that something measures

C. VARIABLE ATTRIBUTES:

(1) The dimension that is measured (length, width, capacity, time, etc.)

(2) The instrument that is used (given that it is appropriate)

(3) The unit of measurement that is chosen (given that it is appropriate)

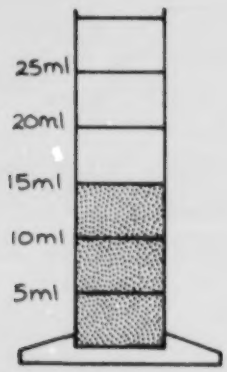
(4) The object(s) measured

D. EXAMPLES OF MEASURING SCIENTIFICALLY:

(1) Jim wanted to find out how long it would take to walk around a path that was 15 miles long. He used his watch and found that it took him 3-1/2 hours.

(2) Jane wanted to see how much her pet mouse weighed. She used an equal arm balance and weights. Jane found that the mouse weighed exactly 90 grams.

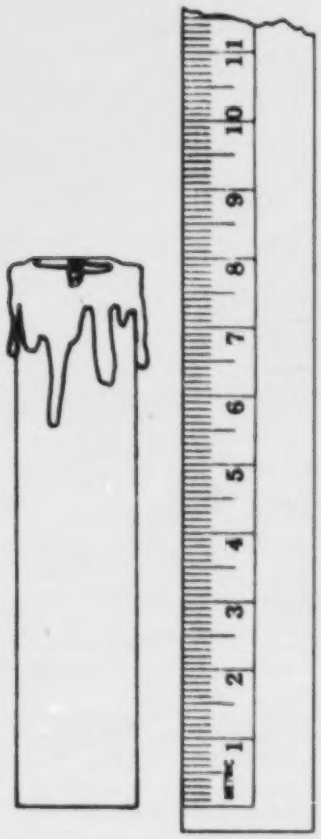
(3) Charlie was measuring water. He used a graduated cylinder as the measuring tool. The graduated cylinder was marked in milliliters. Charlie said, "There are 15 milliliters of water in this graduated cylinder."



(4) Charlie measured a candle that had been burning for 30 minutes. He used a meterstick as the measuring tool and the centimeter as the standard unit of measurement. Charlie held the meterstick next to the candle and said, "This candle is 8 centimeters high."

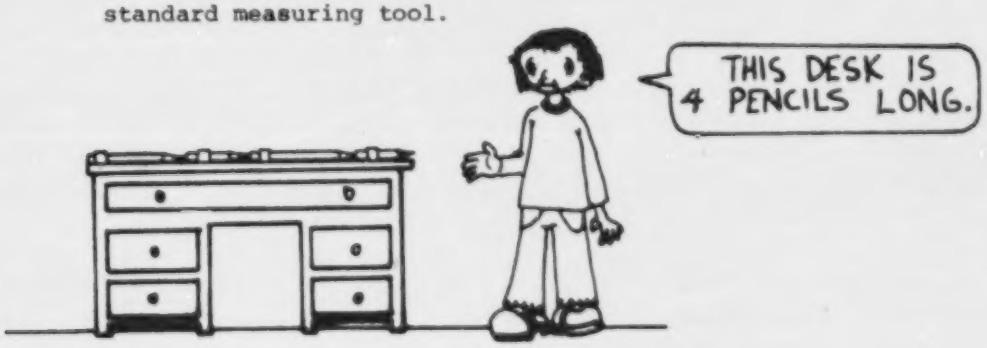
58

(4) Charlie (continued).



E. NONEXAMPLES OF MEASURING SCIENTIFICALLY:

(1) This is an instance in which a person did not use a standard measuring tool.



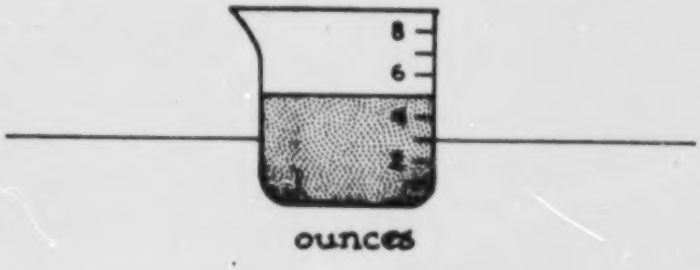
(2) This is an instance in which a person did not find the correct number of standard units.

Charlie wanted to find the height of a candle that had burned for 20 minutes. He used a ruler as the measuring tool. The ruler was marked in inches. He held the ruler next to the candle and said, "This candle is 2 feet high."

(3) This is an instance in which a person did not find the correct numerical value for a given dimension.

Charlie wanted to see how fast the water in a measuring cup evaporated. He used a measuring cup marked in ounces as the measuring tool. He put 6 ounces of water into the measuring cup. The next day he looked at the level of water in the measuring cup. Then

he said, "There are 4 ounces of water in the measuring cup today."



(4) This is an example of another concept (Using numbers) which may be used as a nonexample of Measuring scientifically to prevent overgeneralization.

When Charlie bought a new ivy plant, the owner of the plant store said, "This plant has 8 leaves now. In 6 months it will have 2 times as many leaves!"

"Hmmm," said Charlie. "Two times 8 is 16. (2 x 8 = 16) In six months the plant will have 16 leaves."

F. STATEMENT OF PRINCIPLES:

(1) The accuracy of measurement is dependent upon the use of appropriate measuring instruments.

(2) The more agreement there is among the observed numerical values in repeated measurements, the more precise the measurement is.

(3) The greater the agreement of a single numerical value with the actual or "true" value, the greater the accuracy of the measurement.

(4) Accurate measurement facilitates other processes including Experimenting, Communicating, and Using space/time relationships.

G. SAMPLE PROBLEMS:

(1) Look at the lines below. Choose an appropriate tool, then measure scientifically the length of each line in inches. In the blank next to each line, write the correct number of inches that each line measures.

_____ inches

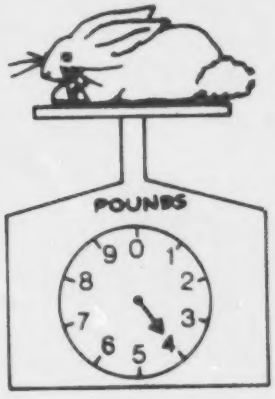
_____ inches

_____ inches

_____ inches

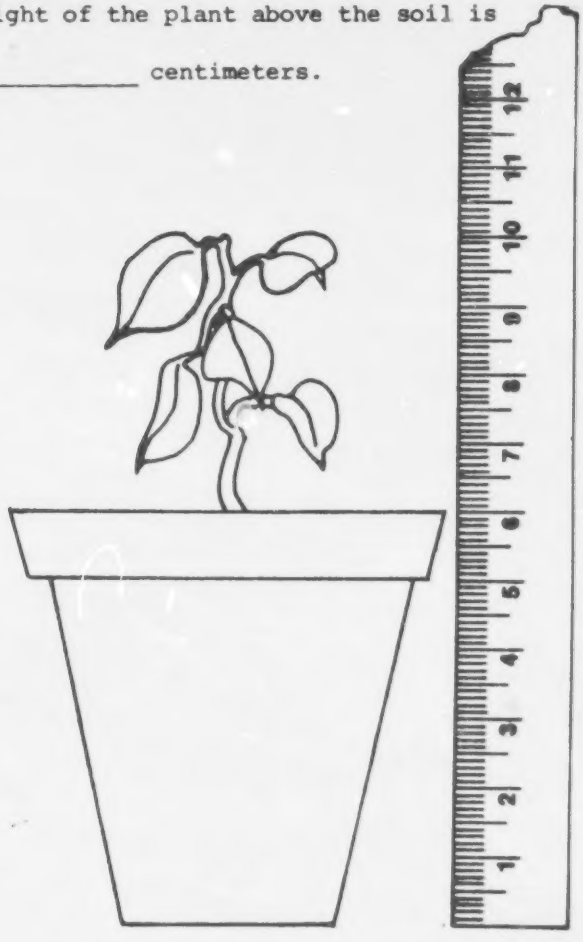
_____ inches

(2) Fill in the blanks with the correct number and standard unit.



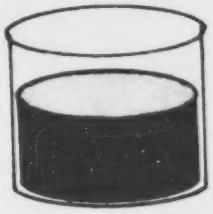
The rabbit weighs _____ _____.
(number) (standard unit)

(3) The height of the plant above the soil is _____ centimeters.



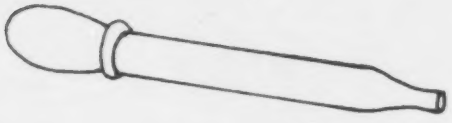
(4) You are going to use the following things in an experiment:

(a jar partly filled with water)



(a graduated cylinder marked off in milliliters)

(a dropper)



How can you find out how many drops are in

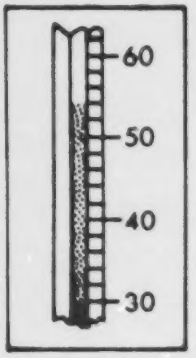
<u>1/2 milliliter</u> of water?

a. Pour some water into the cylinder and guess where 1/2 milliliter would be.

b. Count the number of drops needed to fill the cylinder to the top and divide by 2.

c. Count the number of drops needed to reach the 1 milliliter mark and divide by 2.

(5) Here is part of a Fahrenheit thermometer. What temperature does it show?



a. 50° F
b. 52° F
c. 54° F
d. 55° F

H. KEY VOCABULARY:

to measure

to observe scientifically

to discriminate

to determine

accurate

precise

reliable

appropriate

correct

measurement

dimension

standard unit

ANALYSIS OF USING NUMBERS SCIENTIFICALLY

A. TECHNICAL DEFINITION:

Using numbers scientifically--Applying mathematical operations (addition, subtraction, division, multiplication) correctly to numerical data and/or measurements obtained by scientific observation.

COMMON USAGE DEFINITION:

Using numbers scientifically--Adding, subtracting, multiplying, or dividing numbers found by counting or measuring things in a scientific way.

B. DEFINING ATTRIBUTES:

(1) Finding numbers by counting or measuring things in a scientific way

(2) Adding, subtracting, multiplying, or dividing the numbers correctly

C. VARIABLE ATTRIBUTES:

(1) The mathematical operation used (addition, subtraction, multiplication, or division)

(2) The method of calculating answers (mentally, on paper, with a calculator, with a computer, etc.)

(3) The things which are counted or measured

(4) The standardized measurement scale used

D. EXAMPLE OF USING NUMBERS SCIENTIFICALLY:

(1) Mary lived on a farm. She counted the number of chickens in the chicken house. There were 10 of them. She knew that each chicken laid 1 egg a day. She had all of the eggs that she had picked up in the last 7 days in her refrigerator. She figured out that she should have 70 eggs in the refrigerator.

(2) A student was asked to find the mean height of 4 bean plants. The beans measured: 10 cm, 12 cm, 11 cm, and 13 cm.

First, the student added the four heights:

$$\begin{array}{r} 10 \text{ cm} \\ 12 \text{ cm} \\ 11 \text{ cm} \\ +\ 13 \text{ cm} \\ \hline 46 \text{ cm} \end{array}$$

Then, to find the mean height, the child divided 46 cm by 4. The answer was expressed in decimal notation as shown below:

$$\begin{array}{r} 11.5 \\ 4\overline{)46.0} \\ \underline{4} \\ 6 \\ \underline{4} \\ 2\ 0 \\ \underline{2\ 0} \end{array}$$

Mean height = 11.5 cm

(3) Cindy was watching a grasshopper.

She wanted to find out how far a grasshopper could travel in 2 minutes. The grasshopper hopped 2 meters in the first minute. Cindy thought, "If the grasshopper hopped 2 meters in 1 minute, how many meters would it hop in 2 minutes?" She multiplied 2 x 2 and got 4. She knew that the grasshopper would hop 4 meters in 2 minutes.

(4) Cecil went out to study robins. He looked at all the robins in the field near where he and Cindy worked. There were six robins. Each pair of these birds had a nest. He looked into each nest and counted the eggs. Here is what he found:

Nest 1 3 eggs

Nest 2 4 eggs

Nest 3 2 eggs

He added up the eggs in the nests (3 + 4 + 2 = 9). Then he added the grown-up birds to this (9 + 6 = 15). He told Cindy that if all the eggs hatched he would soon have 15 robins to watch in his study.

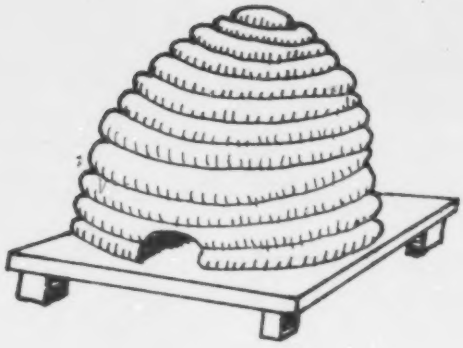
E. NONEXAMPLES OF USING NUMBERS SCIENTIFICALLY:

(1) This is an instance in which a person neither found the numbers by counting or measuring things in a scientific way, nor did the person add, subtract, multiply, or divide correctly.

Cecil was told to look at 3 cubes of butter on a hot plate and to find out which one melted first. Before the butter melted, the cubes of butter in the picture were the same size. One cube was frozen butter, one cube was cold butter from the refrigerator, and one cube was butter at room temperature. He saw that the room-temperature butter melted first, in 1 minute. The cold butter melted next, in 3 minutes. The frozen butter melted last, in 4 minutes.

Cindy asked Cecil how much longer it took the frozen butter to melt than the room-temperature butter. He thought, "It took the room-temperature butter 3 minutes to melt. It took the frozen butter 4 minutes to melt." He thought some more, "4 - 3 = 2." He said, "Cindy, the frozen butter took 2 minutes longer to melt."

(2) This is an instance in which a person did not add, subtract, multiply, or divide correctly.



Cecil's father had a beehive. Each week Cecil took the honey from the hive. Cecil knew that every week this hive of bees made the same amount of honey. The honey weighed 5 pounds. Cecil sold the honey at the Farmers' Market. Cecil told Cindy that they could make some money if they had more beehives. He said that if they had 2 beehives they could sell 12 pounds of honey at the market each week.

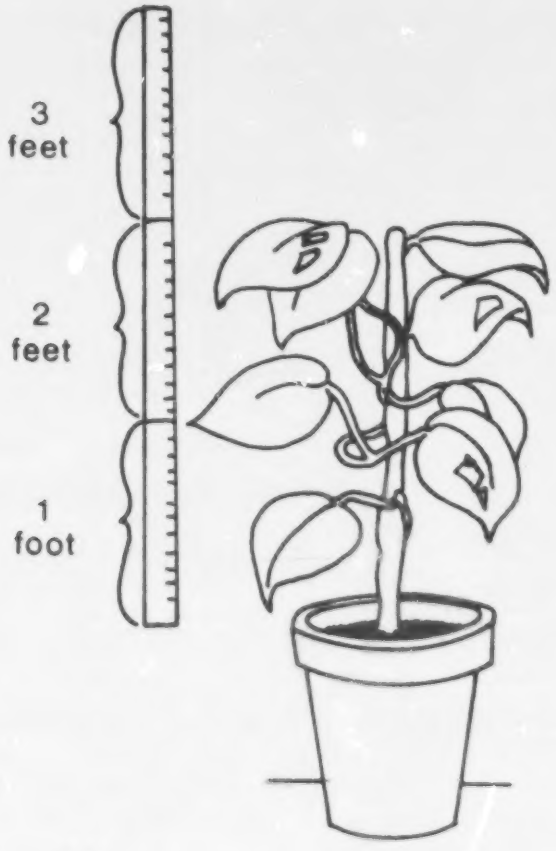
(3) This is an instance in which a person did not find the numbers by counting or measuring things in a scientific way.

Cindy wanted to build a workbench. She built a frame for the workbench. Then she built the legs. Cindy guessed that the frame was about 4 feet wide and 9 or 10 feet long. She looked in the storeroom to find something she could use for a top for the workbench. She found some boards that were 10 feet long and 1 foot wide. She thought to herself, "How many of these boards

do I need for my workbench top? I know 4 feet divided by 1 foot equals 4. I need about 4 boards to make a top for my bench."

(4) This is an example of another concept (Measuring scientifically) which may be used as a nonexample of Using numbers scientifically to prevent overgeneralization.

Charlie bought a new plant. He used a yardstick to find the height of the plant above the soil. He found that the height of the plant above the soil was exactly 2 feet.



(5) This is an example of another concept (Observing scientifically) which may be used as a nonexample of Using numbers scientifically to prevent overgeneralization.

Cecil decided to look at a 10-day-old plant in a scientific way.

Cecil looked at the plant carefully, felt its leaves, and measured it with a ruler. Then he wrote in his report book, "The 10-day-old plant is 3 inches high. It has 5 leaves that are light green in color, smooth, and shiny. Its stem is very straight."

F. STATEMENT OF PRINCIPLES:

(1) Precisions and accuracy are essential for using numbers scientifically.

(2) In general, the greater the number of decimal places to the right of the decimal point, the more accurate the expressed value.

(3) Using numbers is essential for all of the other science processes.

G. SAMPLE PROBLEMS:

(1) What is the average of 10 cm, 12 cm, 11 cm?

a. 2 cm
b. 7 cm
c. 10 cm
d. 11 cm

(2) George won a race by running 100 meters in 10 seconds.

How fast did he run?

a. 1/2 meter per second
b. 1 meter per second
c. 10 meters per second
d. 12 meters per second

(3) Below are the finishing times for a 50-meter race.

Tom:	5 seconds	Sandy:	8 seconds
John:	9 seconds	Mary;	6 seconds

What is the average time for all four runners?

a. 6 seconds
b. 7 seconds
c. 14 seconds
d. 28 seconds

(4) Sue has a bundle of 10 sticks. If she gives 8 of them to her friends, how many tenths of the bundle will she have left?

a. one-tenth (.1) of the bundle
b. two-tenths (.2) of the bundle
c. three-tenths (.3) of the bundle
d. four-tenths (.4) of the bundle

(5) Which of the following is the same as 1,860 pennies?

a. $ 0.186
b. $ 1.86
c. $ 18.60
d. $186.00

H. KEY VOCABULARY:

to add

to subtract

to multiply

to divide

to measure

to observe

accurately

correctly

precisely

scientific data

numbers

mathematical operations

decimal notation

ANALYSIS OF USING SPACE/TIME RELATIONSHIPS

A. TECHNICAL DEFINITION:

Using space/time relationships--Determining the rate of movement of an object(s) based upon observations of the distance the object(s) move and the time required for the movement.

COMMON USAGE DEFINITION:

Using space/time relationships--Knowing the distance an object moved, knowing the amount of time it took to move that distance, and finding the rate at which the object moved by dividing the distance by the amount of time.

B. DEFINING ATTRIBUTES:

(1) Knowing the distance an object moved

(2) Knowing the amount of time it took the object to move that distance

(3) Finding the rate at which the object moved (D/T)

C. VARIABLE ATTRIBUTES:

(1) The object(s) involved

(2) The unit of measure of the distance moved

(3) The unit of measure of the time taken

(4) The rate of movement

D. EXAMPLES OF USING SPACE/TIME RELATIONSHIPS:

(1) Jane observed a small electric train going around one lap of a track. She knew that the amount of time it took the train to complete the lap was 20 seconds. Jane measured the lap. The distance was 4 meters. She divided 4 meters by 20 seconds and said that the rate at which the train moved was 1/5 meter per second.

(2) Casey is a train engineer. He knew that his train traveled 140 miles from Philadelphia to New York. Casey also knew that the amount of time it took the train to go from Philadelphia to New York was 2 hours. Casey divided 140 miles by 2 hours to find that the rate at which his train traveled from Philadelphia to New York was 70 miles per hour.

(3) Mary went on a hike. She took along a pedometer, which showed her how many feet she walked. At the beginning of the trail, Mary set the pedometer at zero and checked the time. It was 11:00 a.m. When she arrived at the end of the trail she looked at her pedometer. It showed that she had walked 2,000 feet. Then Mary looked at her watch. It was 11:10 a.m. Mary divided 2,000 feet by 10 minutes to find that the rate at which she had hiked was 200 feet per minute.

(4) Tom carefully placed an ant on one end of a ruler. The ruler was 12 inches long. The ant crawled in a straight line to the other end of the ruler. Tom used a stopwatch to find that it took the ant 24 seconds to crawl that distance. He then divided the distance that the ant crawled by the amount of time it took the ant to crawl that distance. Tom found that the rate at which the ant had crawled was 0.5 inch per second.

E. NONEXAMPLES OF USING SPACE/TIME RELATIONSHIPS:

(1) This is an instance in which a person did not know the amount of time and did not find the rate of movement.

Paul met Cindy at the zoo. He had walked 4 blocks from his house and arrived at 10:15 a.m. He wanted to find the rate at which he walked from his house to the zoo. He divided the distance that he walked by the time he arrived at the zoo.

Paul said to Cindy, "The rate at which I walked to the zoo was 4 blocks divided by 10:15 a.m."

(2) This is an instance in which a person did not know the distance and did not find the rate of movement.

Amy and her family went to the Art Institute in Chicago. She knew that it took 3 hours to drive from their house to the Art Institute. Amy said that the rate at which they drove was 3 hours.

(3) This is an instance in which the correct rate of movement was not determined.

Robert went to a horse race. He knew that the distance each horse ran was 2 miles. He also knew that the winning horse ran that distance in 1 minute. Robert found that the rate at which the winning horse ran was 1/2 mile per minute by dividing 1 minute by 2 miles.

(4) This is an example of another concept (Measuring scientifically) which may be used as a nonexample of Using space/time relationships to prevent overgeneralization.

Betty filled two 50-milliliter beakers with water. She poured the water from one beaker into a container. Then she poured the water from the other beaker into the container. Betty said, "Each beaker had 50 milliliters of water in it. I know that the amount of liquid doesn't change when poured from a beaker into a container." Betty concluded that there was 100 milliliters of water in the container.

F. STATEMENT OF PRINCIPLES:

(1) Using numbers is essential for using space/time relationships.

(2) Accurate scientific observation and accurate measurement are essential for using space/time relationships.

(3) The more accurate and precise are the determinations of distance and time, the more accurate and precise are the statements of rate of change of position.

(4) The rate of change of position (rate of movement) of a moving object is equal to the distance covered, divided by the time elapsed.

F. SAMPLE PROBLEMS:

(1) Cindy looked at her watch as she left the house to go to the zoo. It was 10:20 a.m. She knew that she had 5 blocks to walk. Cindy looked at her watch when she arrived at the zoo. It was 10:30 a.m. At what rate did Cindy walk to the zoo?

(2) Larry told Jane that he walked 1000 meters from his house to her house. He also told her that it took him 10 minutes to walk that distance. At what rate did Larry walk to Jane's house?

(3) If a race car can go 4 kilometers in 2 minutes, how far can it go in 1 minute?

a. 1/2 kilometer
b. 1 kilometer
c. 2 kilometers
d. 3 kilometers

(4) A girl ran 10 blocks in 8 minutes. How many blocks did she run per minute?

(5) A train tool 16 hours to travel from Chicago to New York City, a distance of 980 miles. On the average, how many miles per hour did the train travel?

H. KEY VOCABULARY:

to divide

to determine

rate

position

time

space

motion

rate of change of position

revolution

rotation

distance

rate of movement

speed

relationship

ANALYSIS OF COMMUNICATING SCIENTIFIC INFORMATION

A. TECHNICAL DEFINITION:

Communicating scientific information--Transmitting to others the results obtained by use of one or more of the processes of science through oral, printed, and/or audio-visual form.

COMMON USAGE DEFINITION:

Communicating scientific information--Reporting to others the results found from one or more of the science activities.

B. RELEVANT ATTRIBUTES:

(1) Finding results from one or more of the scientific activities (involving one or more of the processes of science)

(2) Reporting the results to others

C. VARIABLE ATTRIBUTES:

(1) The method of transmitting the information (oral, printed, audio-visual)

(2) The particular science process(es) involved

(3) The particular kind of results (facts, observations, inferences, predictions, etc.)

(4) The person or persons to whom the information is given

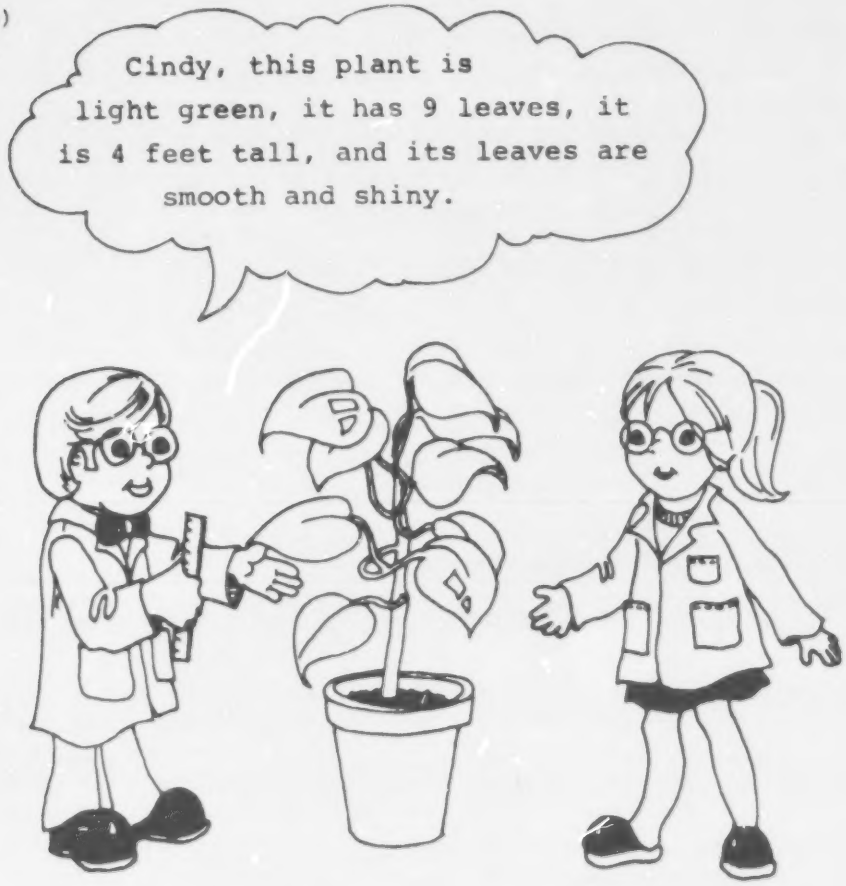
D. EXAMPLES OF COMMUNICATING SCIENTIFIC INFORMATION:

(1) Pam baked four kinds of cookies. One kind of cookie had lemon in it. She asked her mother to tell which kind had lemon in it. Her mother tasted each kind of cookie and wrote down whether or not it had lemon in it. Then Pam read what her mother had written.

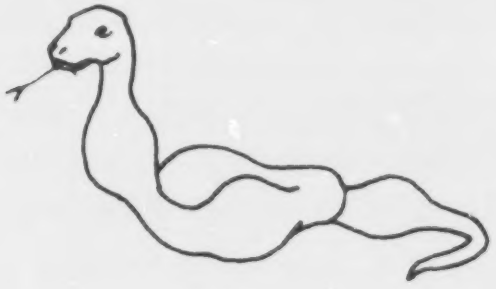
(2) Jack went for a walk in the woods. Each time he saw a bird, he stopped to look at it carefully and to take its picture with a camera. He found out the names of all the birds and showed them his pictures.

(3) Each week Mary cleaned the fish tank in her science classroom. One day Mary observed that 2 of the fish were dead. She wrote a note to her teacher which said that 2 fish had died. Mary's teacher read the note when he got to school the next morning.

(4)



(5) Cindy had a snake. She fed a mouse to the snake each week. At the end of a month the snake had eaten 4 mice. She told Cecil, "This snake will eat 8 mice in 2 months."



E. NONEXAMPLES OF COMMUNICATING SCIENTIFIC INFORMATION:

(1) This is an instance in which the scientific results are not reported to someone else.

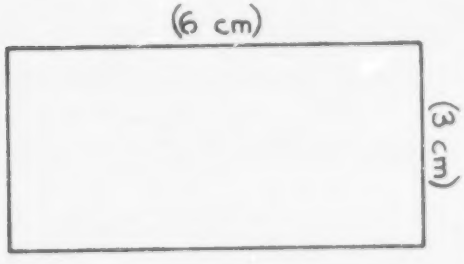
Sandra raised a pig for the county fair. Each week she weighed her pig carefully. Then she wrote down the pig's weight in a notebook that she kept locked in her desk.

(2) This is an instance in which the results are not found from one or more of the processes of science.

Cindy had been watching the ducks on a pond for 10 days. One morning Cindy decided that it was too cold and windy to go out and count the ducks on the pond. She reported to Cecil, "The weather is too bad for there to be any ducks on the pond today."

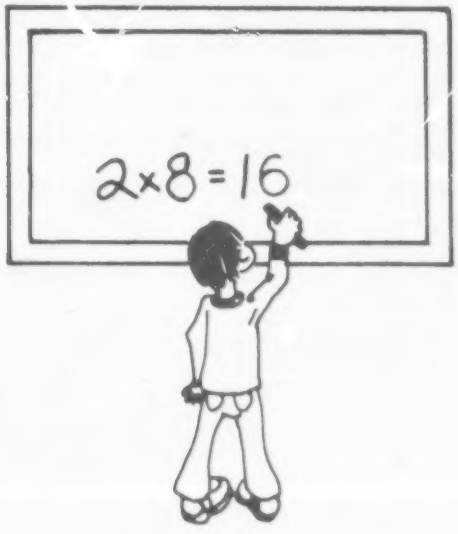
(3) This is an instance in which a person neither found results from one or more of the science processes nor reported the information to others.

Cindy used a ruler to measure the length of this figure:



She thought, "The figure is 5 centimeters long." Cecil asked her how many centimeters long a figure twice as long would be. She thought, "3 x 5 = 15, therefore, it would be 15 centimeters long."

(4) This drawing is an example of another concept (Using numbers scientifically) which may be used as a nonexample of Communicating scientific information to prevent overgeneralization.



(5) This is an example of another concept (Observing scientifically) which may be used as a nonexample of Communicating scientific information to prevent overgeneralization.

Dick observed three cubes of butter on an electric hot plate. He examined the cubes carefully and saw that Cube A melted in 1-1/2 minutes, Cube B melted in 2 minutes, and Cube C melted in 2-1/2 minutes.

Dick recorded all of this information accurately in his report book.

F. STATEMENT OF PRINCIPLES:

(1) If the results obtained from the use of a scientific process are recorded accurately and clearly, then communication of the results will be more accurate than if the results were not recorded carefully.

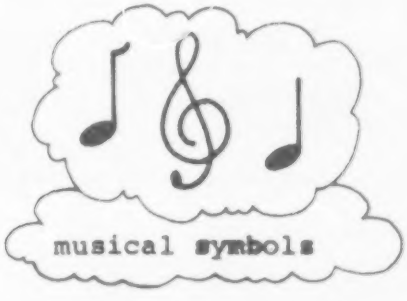
(2) Certain kinds of results obtained by use of a scientific process can be communicated better by one means than another.

(3) Skill in verbal and written expression is essential for effective communication.

(4) The more concise and specific information is conveyed, the more effective is the communication.

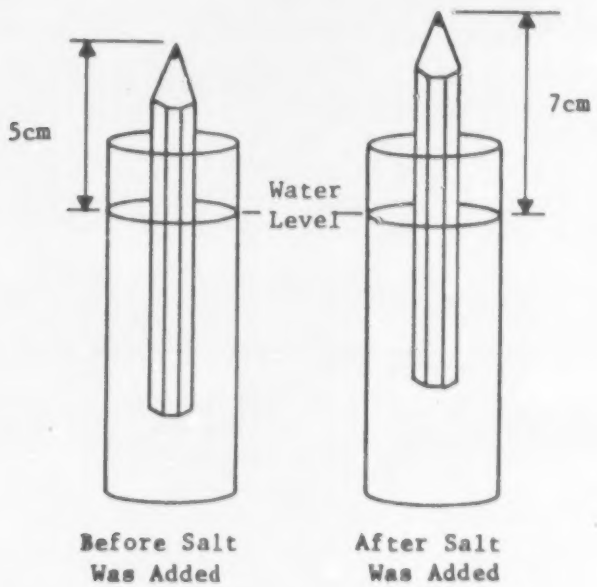
G. SAMPLE PROBLEMS:

(1) Use musical symbols to communicate a song to someone in your class.



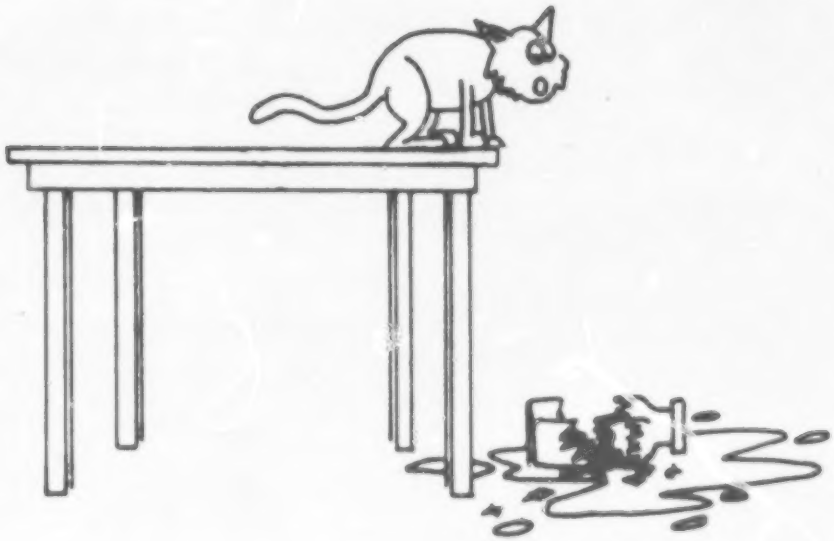
Why are musical symbols better than words for passing songs from one person to another?

(2) An experiment was done to find out what happens to a floating pencil when salt is added to the water. When the pencil was placed in a test tube of pure water, the length of the pencil above water was 5 centimeters. After ten grams of salt were added to the water the length of the pencil above water was measured and found to be 7 centimeters. Here is how the experiment looked.



Communicate the results of this experiment to someone in your class in two or three different ways (oral, written, in graphs, etc.)

(3) Look at the picture below:



Make an inference about what happened in the picture above.

Communicate your inference to someone else without speaking.

_____

_____

_____

H. KEY VOCABULARY:

to communicate

to report

to transmit

information

results

science processes

science activities

data

H. KEY VOCABULARY (continued):

experiment

clearly

accurately

ANALYSIS OF CONTROLLING VARIABLES

A. TECHNICAL DEFINITION:

Controlling variables--Identifying the variables (factors) which may influence the outcome of an experiment, holding the variables constant except for the one variable manipulated, and identifying one responding variable.

COMMON USAGE DEFINITION:

Controlling variables--Deciding which variables could make a difference in the way an experiment comes out, choosing a responding variable, manipulating just one variable, and holding all the other variables constant.

B. DEFINING ATTRIBUTES:

(1) Deciding which variables could make a difference in the way an experiment comes out

(2) Choosing a responding variable

(3) Manipulating just one variable

(4) Holding all the other variables constant

C. VARIABLE ATTRIBUTES:

(1) The object(s) studied in the experiment

(2) The apparatus used in the experiment

(3) The outcome(s) of the experiment

(4) The total number of variables (responding, manipulated and held constant)

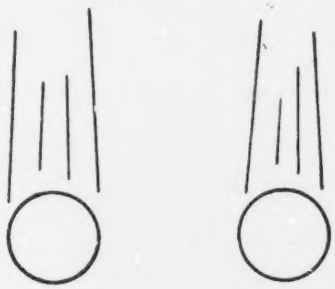
D. EXAMPLES OF CONTROLLING VARIABLES:

(1) "I wonder if bread mold would grow faster in a bright room or a dark room," said Sandy. She decided that the kind of bread, the temperature of the rooms, the amount of light and moisture in the rooms, and the amount of mold put onto the bread might make a difference in the way the experiment came out. She manipulated the amount of light in the rooms. She kept all the other things in the experiment the same for the two pieces of bread. She decided that the amount of mold on each piece of bread after 5 days would be the responding variable.

(2) Dick did an experiment to see if heavy objects would fall faster than lighter objects.

He decided that the following variables could make a difference in the way the experiment came out: weight of the objects, size of the objects, shape of the objects, time at which the objects were dropped, and height from which the objects were dropped.
He chose the order in which the objects hit the floor as the responding variable.
Dick manipulated just one variable (the weight of the objects) by using two rubber balls of different weights. One weighed 7 ounces and the other weighed 12 ounces.
He held constant all the other variables: the size of the balls, the shape of the balls, the time at which the balls were dropped, and the height from which the objects were dropped. He did this by dropping two balls of the same size at the same time from the same height.

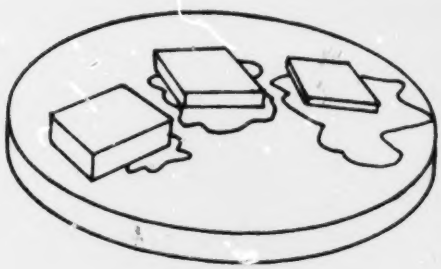
Dick found that both balls hit the floor at exactly the same time.



(3) Jane performed an experiment with three cubes of butter. She wanted to see which cube of butter would melt first on an electric hot plate: a cube of frozen butter, a cube of cold butter from the refrigerator, or a cube of butter at room temperature.

She decided that the following variables might make a difference in the way the experiment came out: temperature of the butter, size of the cubes of butter, and the time at which the cubes were put onto the electric hot plate.
Jane chose the melting time of each cube of butter as the responding variable.
She manipulated only one variable: the temperature of the butter cubes.
She held constant all the other variables. The butter cubes were exactly the same size and were put onto the electric plate at exactly the same time.

Jane observed that the butter at room temperature melted in 1-1/2 minutes, the butter from the refrigerator melted in 3 minutes, and the frozen butter melted in 4-1/2 minutes.



(4) Bob wanted to find out if a piece of paper crushed into a ball would fall slower or faster than a piece of paper that was flat. He decided on the things that could change the way his experiment came out: whether the paper was crushed or flat, the height from which the papers were dropped, and the time at which the papers were dropped. He chose the order in which the papers hit the floor as the responding variable. Bob crushed one paper into a ball and left the other one flat. He held constant all the other things in the experiment.

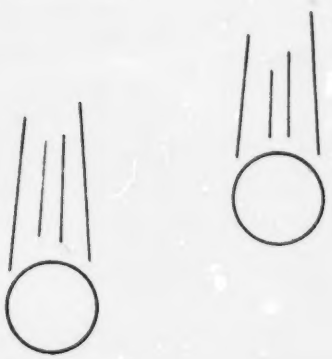
E. NONEXAMPLES OF CONTROLLING VARIABLES:

(1) This is an instance in which all variables besides the responding and manipulated variables were not held constant.

Jane did an experiment to find out if heavy objects would fall faster than lighter objects.

She decided that the following variables might make a difference in the way the experiment came out: weight of the objects, size of the objects, shape of the objects, time at which the objects were dropped, and height from which the objects were dropped.
Jane chose the order in which the objects hit the floor as the responding variable.
She manipulated just one variable, the weight of the objects. To do this she chose two rubber balls, one weighing 8 ounces and the other weighing 14 ounces. But she forgot to control the other variables. The balls were different sizes. Jane dropped the lighter ball a little later than the heavier ball. She also dropped the balls from different heights.

She found that the heavy ball hit the floor before the lighter ball.



(2) This is an instance in which a person did not manipulate just one variable and did not hold all the other variables constant.

Jane did an experiment with seeds.

> She decided that the following variables might make a difference in the way the experiment came out: temperature in which the seeds were placed, type of soil, depth at which the seeds were planted, amount of water given to each seed, and the type of seed. She chose the order in which the seeds came above the surface of the soil as the responding variable. She manipulated two variables: the type of soil used for each seed and the temperature in which the seeds were placed. She used soil from the garden for one seed and soil from a plant store for the other seed. She placed the pot containing one seed in the refrigerator and the pot containing the other seed in a warm spot in the living room.
> Jane forgot to hold the other variables constant. She used one corn seed and one bean seed. She planted one seed about 2 inches below the surface of the soil and the other seed about an inch below the surface. She gave the seed in the refrigerator 20 milliliters of water every day, but she forgot to water the seed in the living room.

At the end of 5 days, neither seed had come above the surface of the soil.

(3) This is an instance in which no variable was manipulated.

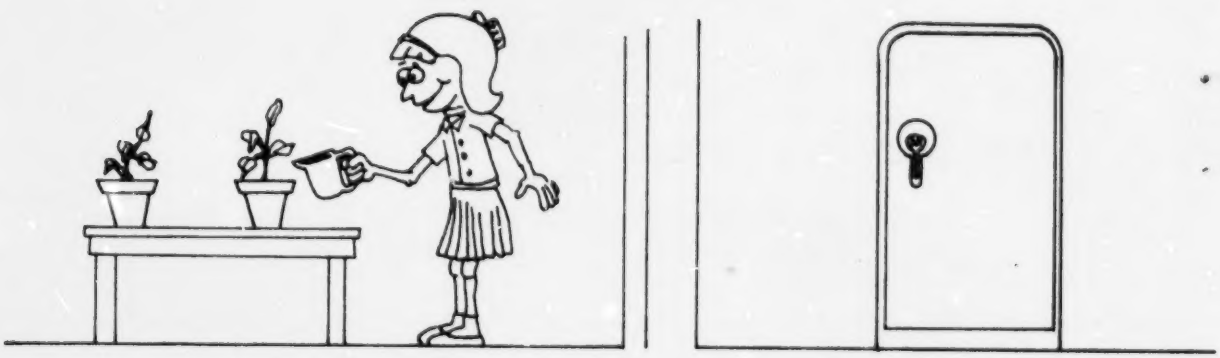
After Jane performed the last experiment with the seeds, Mr. Control said:

> Jane, you did not manipulate just one variable and you did not hold all the other variables constant.

Jane decided to do the experiment again.

She decided the same variables could make a difference in the way her experiment came out: temperature in which the seeds were placed, type of soil, depth at which the seeds were planted, amount of water given to each seed, and the type of seed.
Jane again chose the order in which the seeds came above the surface of the soil as the responding variable.
This time Jane held constant all the variables: the temperature in which the seeds were placed, type of seed, type of soil, depth at which the seeds were planted, and the amount of water given to each seed. She used two bean seeds, took soil from the same bag, and planted each seed exactly 2 inches below the surface of the soil. She put both plants in the same warm spot in the living room and gave each plant 20 milliliters of water every day.

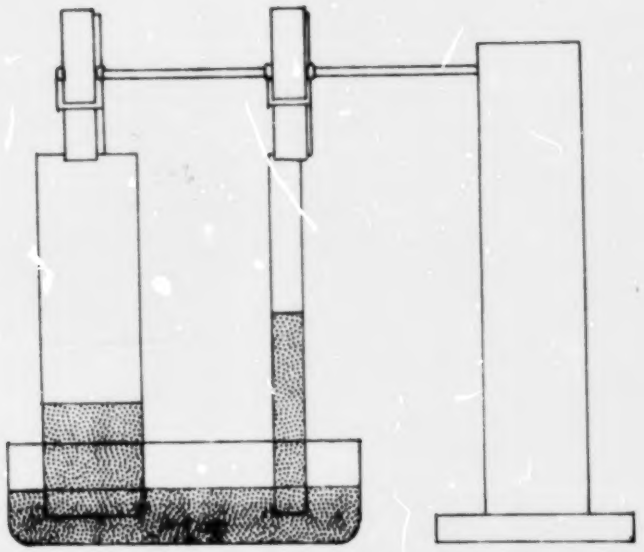
At the end of 4 days, <u>both</u> seeds had sprouted above the surface of the soil.



(4) This is an instance in which no responding variable was chosen.

Dick and Jane did an experiment to see if water would rise at the same rate in blotting papers that were different widths.

They decided which variables could make a difference in the way the experiment came out: width of the paper, length of the paper, temperature of the water, kind of paper, depth of the paper under water, and time at which the papers were put into the water.
The children manipulated just one variable: the width of the blotting paper. They cut one strip 1 inch wide and one strip 3 inches wide.
They held constant all the other variables: length of the paper, kind of paper, and the temperature of the water. They also held constant the depth of the paper under the water and the time at which the papers were put into the water. They held these variables constant by cutting two strips of the same length from the same piece of blotting paper. They put warm water into a dish, then they put the two strips under the water to the same depth at exactly the same time.



(5) This is an example of another concept (Observing scientifically) which may be used as a nonexample of Controlling variables to prevent overgeneralization.

Ellen scientifically observed a leaf on a tree. She counted the number of points on the leaf, then she recorded the length, width, and color in her notebook. Ellen concluded that the leaf was a maple leaf. Then she took two leaves from the same tree and compared them to see if they had the same number of points, were the same length, and were the same color. She chose these things as the experimental variables.

(6) This is an example of another concept (Inferring) which may be used as a nonexample of Controlling variables to prevent overgeneralization.

Jane saw two plants sitting on a table. One plant was green but the other plant was brown and dry.

Plant A is green, but Plant B is brown and dry.
I know that plants need water to live.
I conclude that Plant B has not been watered in several days.
A
B

F. STATEMENT OF PRINCIPLES:

(1) Controlling variables is essential for the process of Experimenting.

(2) The more carefully the variables in an experiment are controlled, the more likely that the results of the experiment will be valid.

(3) If any variable in an experiment is not identified or controlled, the results of the experiment will probably be invalid.

(4) If the manipulated variable in an experiment is not manipulated properly, the results of the experiment will probably be invalid.

(5) If the responding variable in an experiment is not identified or measured properly, the results of the experiment will certainly be invalid.

(6) Controlling variables in an experiment permits more exact observations to me made and more precise inferences to be drawn.

G. SAMPLE PROBLEMS:

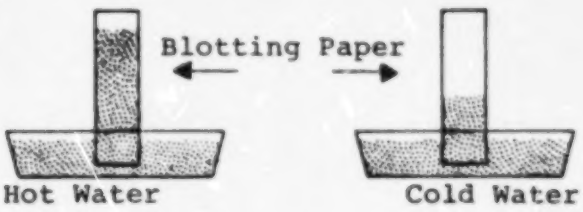
(1) An experiment was done to find out how fast three solid steel balls would roll down an inclined plane.

2 grams 8 grams 12 grams

What was the manipulated variable in this experiment?

a. the shape of the objects
b. the weight of the objects
c. the size of the objects

(2) The drawing below shows an experiment to find out if hot water will rise faster than cold water in blotting paper. Identical strips of blotting paper were placed into both containers of water at the same time.



What variable was manipulated in this experiment?

a. the temperature of the water
b. the kind of material
c. how fast the water rises
d. the starting time

What was the responding variable in this experiment?

a. the temperature of the water
b. the kind of material
c. how fast the water rises
d. the starting time

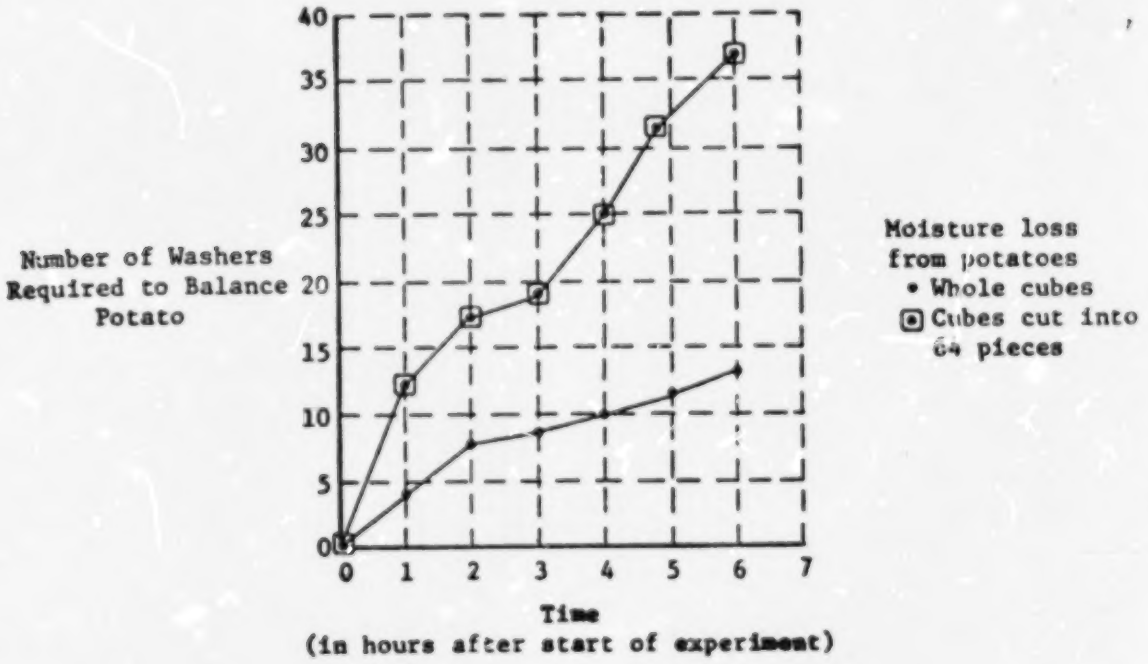
In this experiment, what were the kind of material, the kind of liquid, and the starting time?

a. manipulated variables
b. responding variables
c. variables held constant

(3) An experiment was performed to answer this question: "Will fruit cut in the shape of a cube lose weight faster than fruit cut in the shape of a cylinder?" A cube and a cylinder were cut from a fruit. The two pieces weighed exactly the same. During the day, the experimenter weighed each piece once every hour.

Name the responding and manipulated variables in this experiment and tell which variables were held constant.

(4) An experiment was performed to measure the moisture loss of a potato under different conditions using an equal-arm balance and washers. Here are the results.



What is the responding variable in this experiment?

a. the shape of the potato pieces
b. the weight of the potato
c. the amount of moisture loss
d. the time in which changes took place

H. KEY VOCABULARY:

to experiment

to control variables

to identify

to manipulate

H. KEY VOCABULARY (continued):

to respond

to hold constant

experimental variable

manipulated variable

responding variable

variable held constant

outcome

results

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Center Planning and Policy Committee

Richard A. Rossmiller
Wayne Otto
Center Co-directors

Wayne Otto
Area Chairperson
Studies in Reading, Language and Communication

Marvin J. Fruth
Area Chairperson
Studies of Implementation of Individualized Schooling

Herbert J. Klausmeier
Area Chairperson
Studies of Instructional Programming for the Individual Student

James M. Lipham
Area Chairperson
Studies of Administration and Organization for Instruction

Thomas A. Romberg
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Studies in Mathematics and Evaluation of Practices in Individualized Schooling

Associated Faculty

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Professor
Psychology

B. Dean Bowles
Professor
Educational Administration

Thomas P. Carpenter
Associate Professor
Curriculum and Instruction

W. Patrick Dickson
Assistant Professor
Child and Family Studies

Marvin J. Fruth
Professor
Educational Administration

John G. Harvey
Professor
Mathematics
Curriculum and Instruction

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Child and Family Studies

Dale D. Johnson
Professor
Curriculum and Instruction

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Professor
Educational Administration

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Curriculum and Instruction

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Professor
Curriculum and Instruction

Gary G. Wehlage
Associate Professor
Curriculum and Instruction

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